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LABORATORY INVESTIGATION OF ICING IN THE CARBURETOR AND SUPERCHARGER INLET ELBOW OF AN AIRCRAFT ENGINE

II - DETERMINATION OF THE LIMITING-ICING CONDITIONS

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and Donald R. Mulholland

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

LABORATORY INVESTIGATION OF ICING IN THE CARBURETOR AND SUPERCHARGER INLET ELBOW OF AN AIRCRAFT ENGINE

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SUMMARY

The carburetor and engine-stage supercharger assembly of a fighter aircraft were laboratory-tested to determine the icing characteristics of the induction system under three simulated engine power conditions with varying carburetor-air temperature, relative humidity, simulated-rain injection, rain and fuel temperature, fuel-air ratio, and fuel of different distillation characteristics. All runs were of 15-minute duration, after which the carburetor and supercharger inlet elbow were visually inspected for ice formations. The limits of visible icing and serious icing, which is defined by a 2-percent reduction in air flow in a 15-minute test period, were found to form at progressively lower air temperatures and heat contents as engine power was increased. Relatively small accumulations of ice on the throttle plates caused more serious reductions in air flow than large deposits of ice in the supercharger inlet elbow. Turbulences below the throttles and circulation of fuel in the inlet elbow were responsible for severe cooling of the throttles and heavy deposits of ice on the under surfaces owing to the refrigeration effect of the fuel evaporation. This effect was less noticeable as throttle angle and air flow were increased for high power conditions.

Variation of fuel-air ratio and fuel and water temperatures had no consistent effect on icing measured by the apparatus used during the tests; reductions of relative humidity in the presence of free-water injection did, however, increase the severity of icing because

of the corresponding reduction in the heat content of the air-water vapor mixture. Fuels of low volatility were found to produce less serious icing and the use during most of the tests of a more volatile fuel than is generally required for most airplanes produced conservative results.

INTRODUCTION

As part of an investigation requested by the Air Technical Service Command, Army Air Forces, on the icing characteristics of a fighter airplane induction system, tests were run on the part of this induction system consisting of a twin-barrel injection-type carburetor mounted on an engine-stage supercharger assembly. Icing tests were conducted at the NACA Cleveland laboratory in the fall of 1944 at three simulated engine powers to study the effects of carburetor-air temperature and relative humidity with and without simulated-rain intake, rain-water temperature, fuel-air ratio, fuel temperature, and of several fuels having different distillation characteristics.

Previous experience in icing investigations of aircraft induction systems (references 1 and 2) has shown that the severity of the icing experienced in a given induction system under fixed power operation is largely dependent upon carburetor-air heat content and total water content. This result is to be expected because the icing phenomenon is essentially a refrigeration process depending upon the amount of water available and the heat removal necessary to produce the ice. Specific combinations of carburetor-air heat content and total water content are therefore defined as the limiting-icing conditions as was done in references 1 and 2 and the other conditions are separately investigated as independent variables.

The controlled variables were measured at the carburetor deck or in the air stream near the carburetor and their values do not necessarily correspond to known atmospheric conditions because of the unknown effects of the carburetor air scoop, the ducting, the turbosupercharger, and the intercooler in this induction system. The limiting-icing conditions presented are therefore in terms of conditions in the air stream at the carburetor and are not directly related to atmospheric conditions in flight. The relation between these two sets of conditions will be established and subsequently reported as a result of a flight icing investigation of the induction system of the fighter airplane.

The ranges of values for the experimental variables selected for this investigation were arbitrarily chosen to produce only ice formations of the fuel-evaporation and throttling types because the presence of the turbosupercharger and the intercooler effectively prevents the occurrence of impact-icing conditions at the carburetor.

The arbitrary criteria for the determination of the limiting-icing conditions divide the test results into three categories: no visible icing, visible icing, and serious icing. In each case the selection of the proper category is the result of a visual inspection of the carburetor and supercharger inlet elbow at the end of a 15-minute test run. The icing is considered serious if the flow-rate reduction exceeds 2 percent of the initial value at any time within the 15-minute test period. The classification of test results in the serious-icing category is based on the assumption that a reduction of air flow exceeding 2 percent would seriously affect the operation of the engine. The 15-minute time interval was selected on the assumption that it is a reasonable maximum period during which the icing conditions at the carburetor deck would not change in flight because of changes in ambient atmospheric conditions or other changes imposed by the pilot as the result of the gradual loss of engine power caused by the icing.

APPARATUS AND TEST PROCEDURE

The apparatus for conducting the icing investigation on the carburetor mounted on an engine-stage supercharger is described in detail in reference 3. The design and operation of the test equipment insures control of charge-air temperature, humidity and free-water content, and of fuel and water temperature during each test run. The air pressure at the carburetor deck was maintained equivalent to a simulated altitude of 2000 feet. The test conditions and the range of variables are shown in table I.

In the determination of the limiting-icing conditions, the procedure was similar to that used in pervious induction-system icing tests (references 1 and 2). When the desired test conditions of air-flow rate, temperature, and humidity had been established, the fuel and simulated-rain water were diverted from their bypass lines into the induction system at the previously selected temperatures and flow rates. Thereafter, at regular intervals during the 15-minute test runs, measurements were taken of air-flow, fuel-flow, and carburetor-deck conditions. At the end of the test period the air, the fuel, and the water flows were cut off and the ice formations, if any, were examined either through the observation windows or by dismantling the induction system. The criteria previously discussed were then applied to the results to classify the type of icing.

DISCUSSION

Limiting-Icing Conditions

Presentation of results. - The results of test series 1 at simulated normal rated power, series 2 at simulated high cruising power, and series 3 at simulated low power are presented on coordinates of heat content and total water content of air in figures 1, 2, and 3, respectively. The limiting-conditions curves for visible and serious icing represent the upper limits for these conditions. For all tests with simulated-rain intake, the charge air was saturated. The curves of constant relative humidity and water injection in excess of saturation are superimposed for ease in interpreting the results.

The limiting-conditions curves shown in figures 1, 2, and 3 are replotted in figures 4, 5, and 6, respectively, in terms of carburetor-air temperature and total water content. These curves were replotted because carburetor-air temperature is a more tangible quantity than carburetor-air heat content and carburetor-air temperature is usually indicated on the instrument panel of the airplane. Carburetor-air temperature can, however, be considered a limiting-icing condition only when the air is saturated in the presence of free water or when free water is not present because only under these conditions is carburetor-air temperature directly related to heat content. The temperature maximums of the two limiting-conditions curves on carburetor-air-temperature and total-water-content coordinates represent minimum temperatures below which either visible or serious icing may occur. If the conditions of operation (at the carburetor deck) lie between the two limiting-conditions curves, the visible icing encountered may become serious after 15 minutes of operation.

The effects of the three power conditions on the icing characteristics are presented in figure 7 where the limits of visible and serious icing are plotted in terms of absolute water content against carburetor-air temperature and of absolute water content against carburetor-air heat content. As power is increased, the icing limits recede toward the freezing levels of temperature and heat content below which impact icing occurs on the air-metering parts of the carburetor, in addition to fuel-evaporation icing below the throttles.

Location and cause of ice formations. - Most of the serious icing was characterized by heavy ice formations on the throttle plates and surrounding wall surfaces. The free water from which this ice formed was evidently supplied by the simulated rain and by condensation of water from the air stream when it was cooled by fuel evaporation and pseudoadiabatic expansion past the throttles. The throttle plates were similarly cooled by fuel evaporation in the turbulent wake below the plates and by direct contact with the expanding air stream.

During all tests with conditions that caused serious icing on the throttle plates, heavy icing also took place in the supercharger inlet elbow below the carburetor. Owing to the large cross-sectional area in the elbow, however, even very large deposits of ice in this area did not form the critical point for reduction in air flow. A typical example of such icing is shown in figure 8(a).

The throttle icing (fig. 8(b)) was progressively less severe for the runs in which the initial air-flow rates were 4620, 5775, and 7700 pounds per hour and the corresponding throttle angles were 27°, 37°, and 50°. This result is to be expected because the pseudoadiabatic expansion, the turbulent mixing below the throttles, and therefore the degree of cooling are decreased as the throttle angle increases. Further evidence that the icing of the throttles is largely dependent upon throttle angle rather than upon rate of air flow is shown by the results of tests that were performed at wide-open throttle and an air-flow rate of 4620 pounds per hour. These results showed that no serious icing occurred at temperatures as low as 35° F even with simulated rain flowing in at the rate of 250 grams per minute. Previously, with the same simulated-rain injection and air-flow rate and the normal throttle angle of 27°, serious icing occurred at a carburetor-air temperature of 50° F. The limits of serious icing therefore recede toward the region of higher total water content and lower heat content or carburetor-air temperature as the throttle angle is increased to obtain higher air flows.

Although no ice of the fuel-evaporation type formed on the fuel-metering venturis or impact tubes, some ice did form on the fuel nozzle and caused fuel metering to become very erratic.

Effects of Other Variables on Icing Characteristics

Criterion for determination of effect of variables. - The criterion chosen for determining the effect of changes in fuel-air ratio, variation of relative humidity in the presence of simulated-rain injection, variation of fuel and simulated-rain temperature, and changes in fuel-distillation characteristics was comparisons of minimum air flows occurring within 15 minutes of operation under icing conditions previously selected from the curves of limiting-icing conditions. In each of the series, one of the aforementioned conditions was varied while the others were maintained constant. This method of investigation did not permit quantitative evaluation of the effect of the variables but, when a change in the varied condition affected the severity of the icing, a trend could be detected in the successive curves of air flow plotted against time, as shown in figures 9 to 13.

In some cases curves of air flow against time were so erratic that no consistent trend was discernible and, because these curves usually fell within the range of normal variation of test results, it was concluded in each case that the variable in question had no effect on the icing characteristics as manifested by minimum air flow and rate of air-flow drop.

Effect of varied fuel-air ratio. - The object of test series 4 was to determine whether changes of fuel-air ratio affect the icing characteristics of the induction system. In most cases, whether for a light-icing condition as shown in figure 9(a) or for heavy-icing conditions as shown in figures 9(b) and 9(c), the results show that the air-flow against time curve for a very rich fuel-air ratio of 0.125 falls very close to the curve resulting from operating at a lean fuel-air ratio of 0.050. The runs performed at fuel-air ratios between these values fall on either side of the values with no set order or progression. Apparently variation in fuel-air ratio between the values of 0.050 and 0.131 has no consistent effect on the icing of this induction system within the limits of experimental error with this apparatus.

A possible explanation of this behavior is that, between the point of fuel injection and the supercharger impeller for these conditions, the intake air becomes saturated with respect to the fuel at the lowest fuel-air ratio tested (0.050) and no further fuel-evaporation cooling effect results from injecting fuel at a greater rate.

Effect of simulated-rain flow in presence of unsaturated air. - Rain is frequently encountered in flight when the air is not saturated with water vapor. Test series 5 was run to determine the effect of this condition on icing.

When the carburetor-air temperature was maintained at 40° F (fig. 10(a)), the results obtained were inconclusive because the curves showing rate of air flow varied widely with relative humidity without showing any trend. In the tests in which the air temperature was 60° F (fig. 10(b)), lowering the relative humidity permitted serious icing at a temperature that normally would lie beyond the range of serious icing. The reduced relative humidity at a fixed dry-bulb temperature represents a diminution in heat content of the air stream and, consequently, as the heat content drops below the value for the limit of serious icing (23 Btu/lb) as shown in figure 3, the icing becomes serious. Further lowering of the heat content by lowering the humidity increased the severity of the icing.

Effect of varied fuel and water temperatures. - The runs of test series 6 (fig. 11) show that varying the fuel temperature between 9° and 80° F at a carburetor-air temperature of 40° F had no predictable effect on the icing characteristics of this induction system, especially at relatively high water contents. When the fuel temperature was varied over the range from 9° to 80° F, the heat content increased 2.8 Btu per pound of fuel-air mixture, which is probably offset by greater fuel evaporation. This small change in heat content would be critical only in borderline cases of icing.

For similar reasons, varying the temperature of the simulated rain (test series 7) between 34° and 59° F had as little effect on the icing as the variation of the fuel temperature (fig. 12). This variation in the simulated-rain temperature between 34° and 59° F caused a change of only 0.54 Btu per pound of water-air mixture at the lowest air-flow rate tested with a water-flow rate of 750 grams per minute.

Effect of fuel-distillation characteristics. - The results of test series 8 (fig. 13) show that different fuels produce different icing characteristics. The more volatile the fuel, as shown by the distillation curves (fig. 14), the more severe was the icing. The AN-F-22 fuel is the most volatile of those tested and usually gave the greatest drop in air flow. A less volatile fuel, 28-R, gave less severe icing than AN-F-22 fuel but S-4 reference fuel, which has practically no light fractions, in most cases caused practically no air-flow reduction (fig. 13). This performance results from the higher vapor pressures of the most volatile fuel causing the evaporation of greater amounts of each fraction. An increase in the amount of fuel evaporated represents an increase in cooling, which causes more serious icing.

Throughout the limiting-icing-conditions determination and the other icing tests, with the exception of test series 8, AN-F-22 fuel was used exclusively. The use of this fuel, which is more volatile than those in common use in service airplanes, would tend to make the results of the icing tests slightly conservative.

SUMMARY OF RESULTS

From laboratory tests to determine the limiting-icing conditions of the carburetor and supercharger assembly, the following results were obtained:

1. Limits of visible and serious icing formed at progressively lower air temperatures and air heat contents for increases in engine power.

2. Serious reductions in air flow were caused by icing on the throttle plates and adjacent wall surfaces.

3. High throttle angles caused icing to be less serious because pseudoadiabatic expansion and turbulent mixing below the throttles were decreased.

4. Variation of the fuel-air ratio between 0.050 and 0.131 had no consistent effect on the icing characteristics of this carburetor-engine combination within the range of values of carburetor-air temperature and total water content normally associated with serious icing.

5. Free water in the presence of air at relative humidities less than saturation caused serious icing at carburetor-air temperatures above the usual limiting-icing temperature because of the reduction of air heat content as relative humidity was decreased.

6. Variations of fuel temperature from 9° to 80° F and of simulated-rain water temperature from 34° to 59° F did not appreciably change the icing characteristics of this induction system within the range of values of carburetor-air temperature and total water content normally associated with serious icing.

7. The severity of the icing increased with the volatility of the fuel used.

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REFERENCES

1. Essex, Henry A., and Galvin, Herman B.: A Laboratory Investigation of Icing and Heated-Air De-Icing of a Chandler-Evans 1900 CPB-3 Carburetor Mounted on a Pratt & Whitney R-1830-C4 Intermediate Rear Engine Section. NACA ARR No. E4J03, 1944.

2. Galvin, Herman B., and Essex, Henry A.: A Laboratory Investigation of the Icing Characteristics of the Bendix-Stromberg Carburetor Model PD-12F5 with the Pratt & Whitney R-1830-C4 Intermediate Rear Engine Section. NACA ARR No. E4J18, 1944.

3. Mulholland, Donald R., Rollin, Vern G., and Galvin, Herman B.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of an Aircraft Engine. I - Description of Setup and Testing Technique. NACA MR No. E5L13, 1945.

TABLE I - TEST CONDITIONS AND RANGE OF TEST VARIABLES

Test series	Engine operating conditions			Carburetor-air temperature (°F)	Moisture content		Water temperature (°F)	Fuel temperature (°F)	Fuel
	Air flow (lb/hr)	Fuel-air ratio	Power (a)		Relative humidity (percent)	Simulated-rain injection (grams/min)			
1	7700	0.095	N.R.	20-82	25-100	[b]0-1000	40	40	AN-F-22
2	5775	0.080	H.C.	22-97	13-100	[b]0-1000	40	40	AN-F-22
3	4620	0.080	L.C.	1-102	19-100	[b]0-1000	40	40	AN-F-22
4	4620	0.050-0.125	L.C.	40	80	(c)	(c)	40	AN-F-22
	4620	0.051-0.131	-do--	40	100	(c)	(c)	40	AN-F-22
	4620	0.050-0.125	-do--	40	100	[b]100	40	40	AN-F-22
5	4620	0.080	L.C.	40	62-100	100	40	40	AN-F-22
	4620	.080	-do--	60	17-100	100	40	40	AN-F-22
6	4620	0.080	L.C.	40	69	(c)	(c)	9-80	AN-F-22
	4620	.080	-do--	40	100	(c)	(c)	10-70	AN-F-22
	4620	.080	-do--	40	100	[b]100	40	10-70	AN-F-22
7	4620	0.080	L.C.	40	100	[b]250	35-55	40	AN-F-22
	4620	.080	-do--	40	100	[b]750	34-59	40	AN-F-22
	4620	.080	-do--	50	100	[b]250	35-56	40	AN-F-22
8	4620	0.080	L.C.	40	100	(c)	(c)	75	S-4,28-R, AN-F-22
	4620	.080	-do--	40	100	[b]250	40	75	Do.
	4620	.080	-do--	50	81	(c)	(c)	75	Do.
	4620	.080	-do--	50	100	(c)	(c)	75	Do.
	4620	.080	-do--	50	100	[b]250	40	75	Do.

[a]N.R. - Normal rated power, 2600 rpm
H.C. - High cruising power, 2300 rpm
L.C. - Low cruising power, 2200 rpm
[b]Simulated-rain injection in excess of saturation.
[c]No simulated-rain injection.

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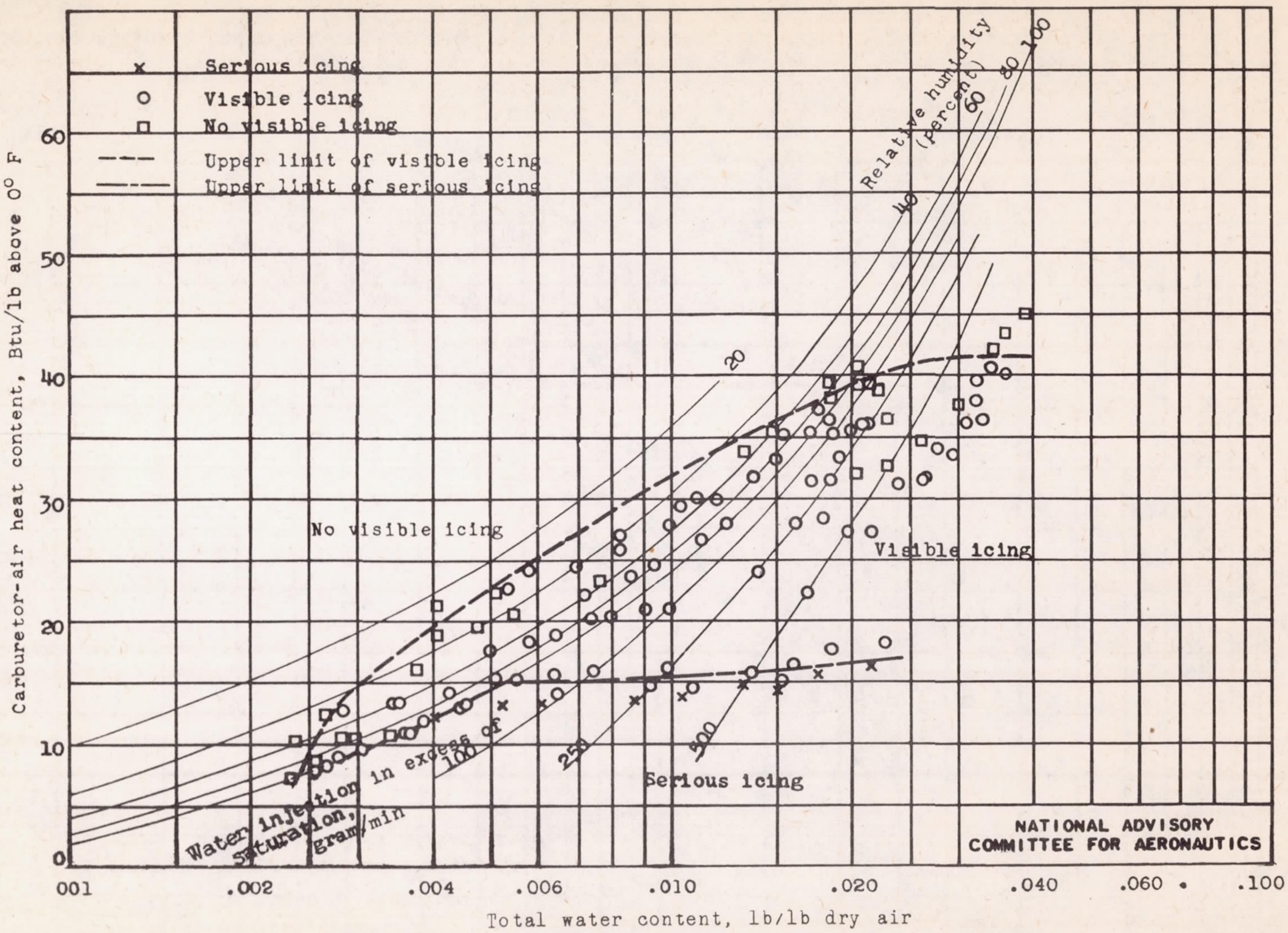

Figure 1. - Limiting-icing conditions of carburetor-air heat content and water content at simulated normal rated power obtained in test series 1. Initial air flow, 7700 pounds per hour; initial fuel-air ratio, 0.095; pressure altitude, 27.82 inches mercury absolute.

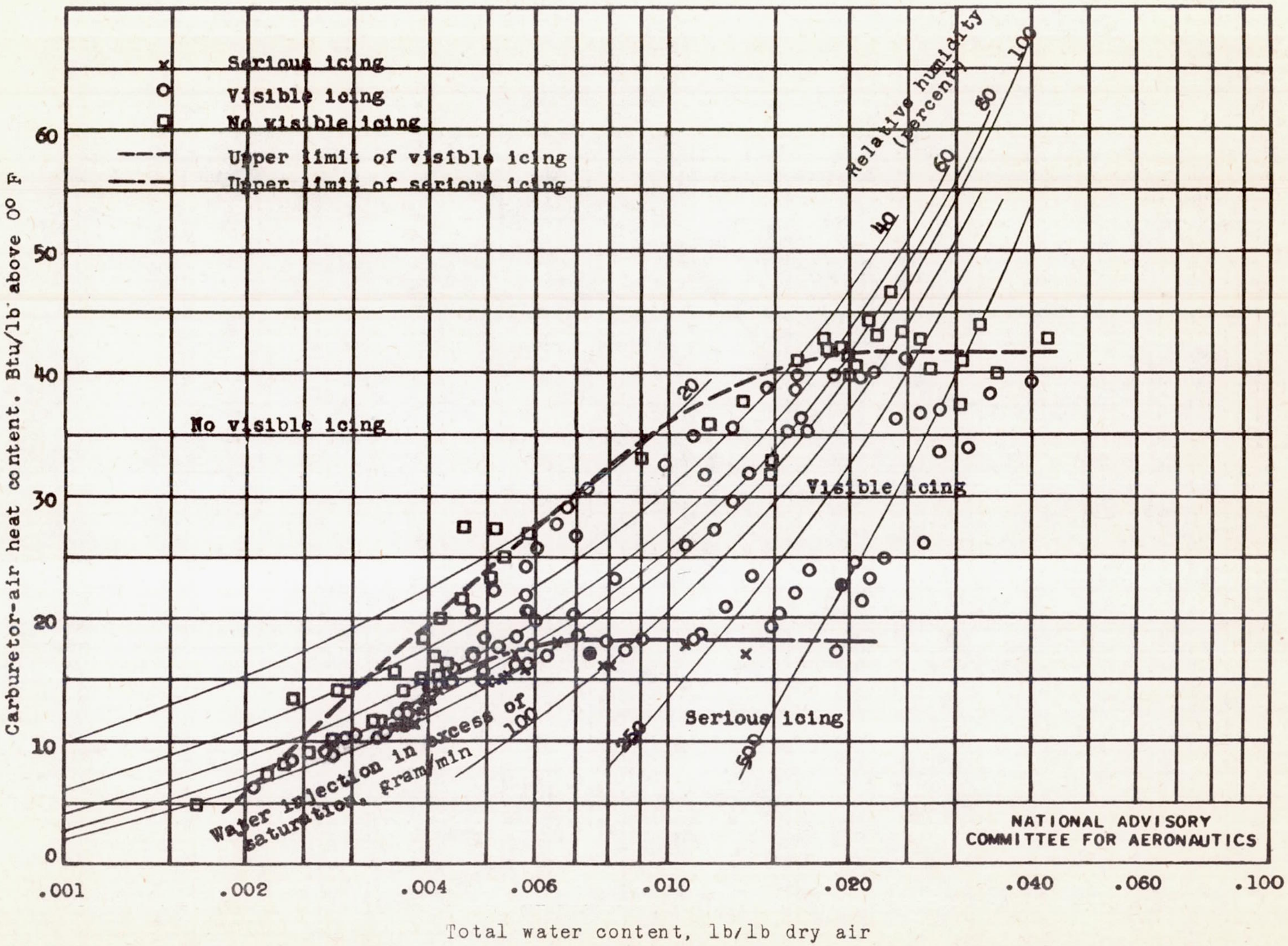

Figure 2. - Limiting-icing conditions of carburetor-air heat content and water content at simulated high cruising power obtained in test series 2. Initial air flow, 5775 pounds per hour; initial fuel-air ratio, 0.080; pressure altitude, 27.82 inches mercury absolute.

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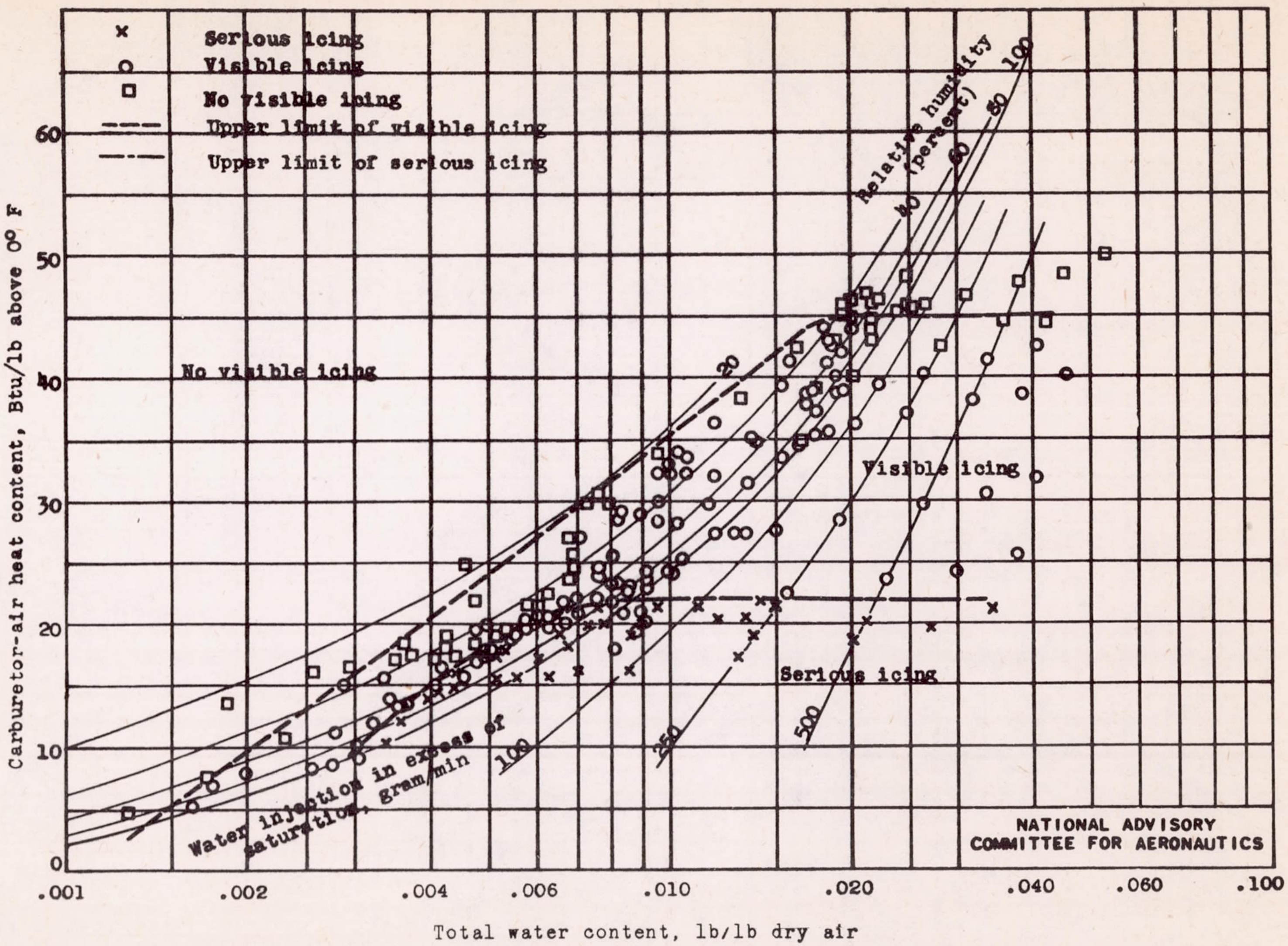

Figure 3. - Limiting-icing conditions of carburetor-air heat content and water content at simulated low cruising power obtained in test series 3. Initial air flow, 4620 pounds per hour; initial fuel-air ratio, 0.080; pressure altitude, 27.82 inches mercury absolute.

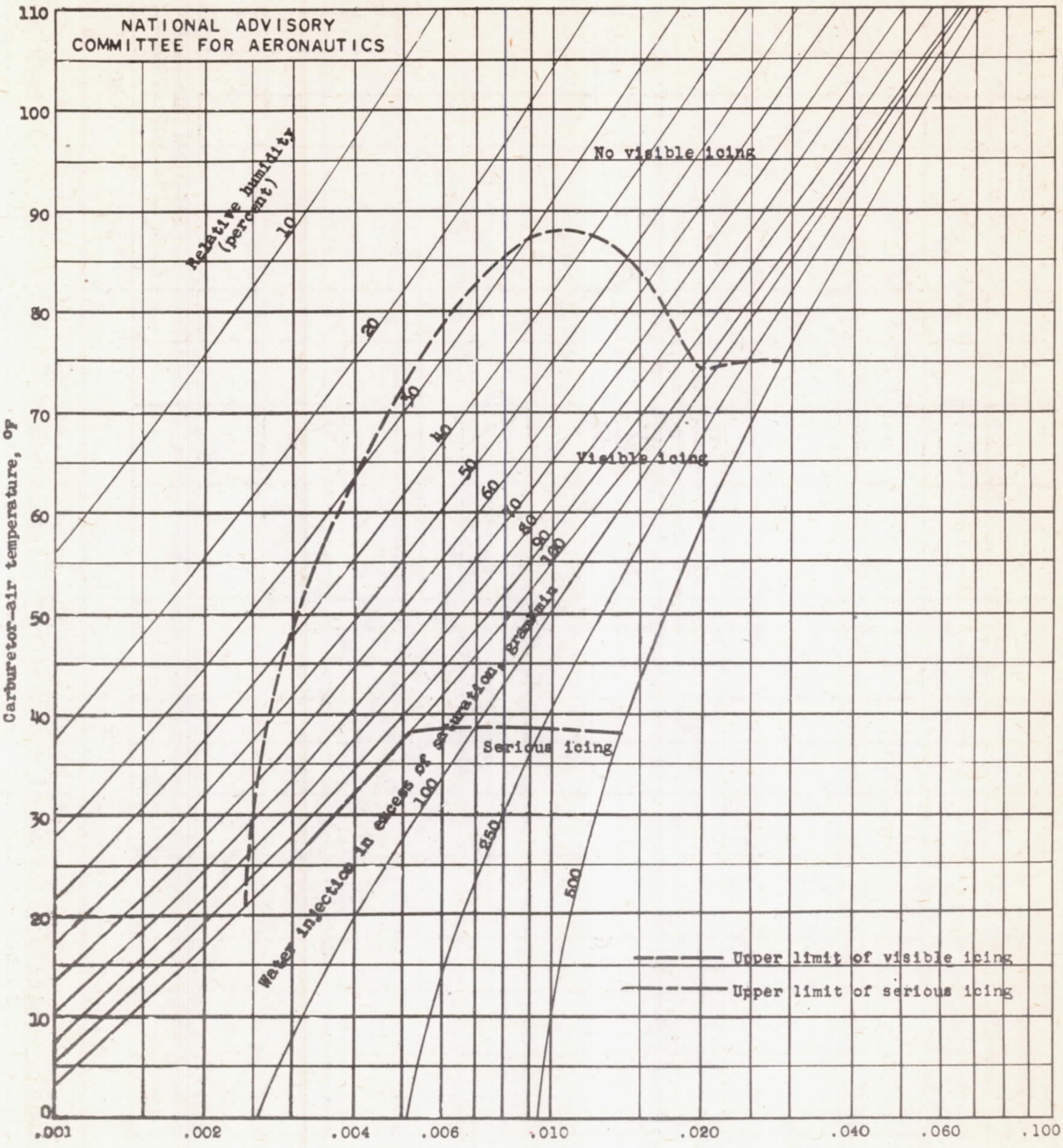

Figure 4. - Limiting-icing conditions of carburetor-air temperature and water content at simulated normal rated power obtained in test series I. Initial air flow, 7700 pounds per hour; initial fuel-air ratio, 0.095; pressure altitude, 27.82 inches mercury absolute.

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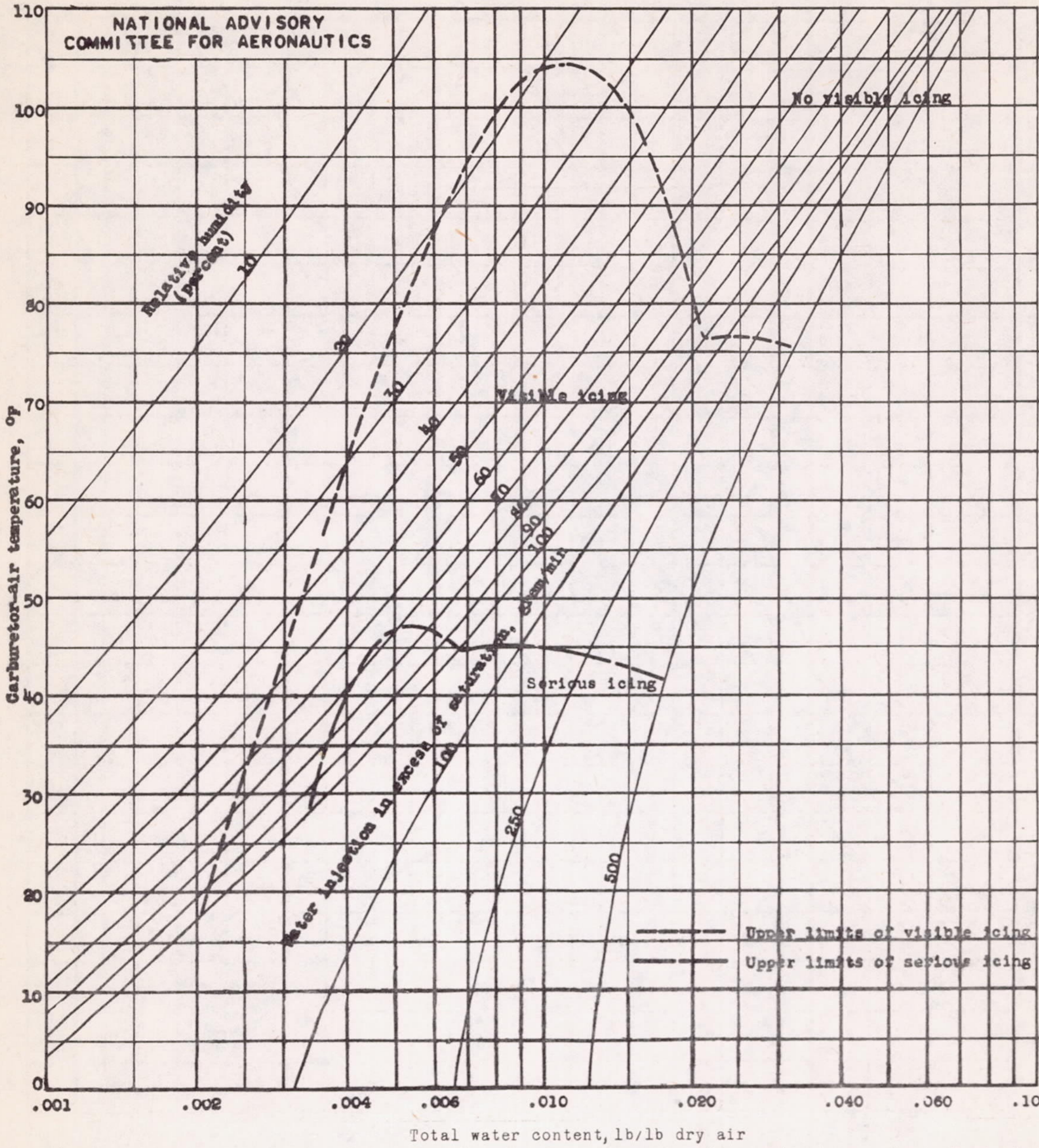


Figure 5. - Limiting-icing conditions of carburetor-air temperature and water content at simulated high cruising power obtained in test series 2. Initial air flow, 5775 pounds per hour; initial fuel-air ratio, 0.080; pressure altitude, 27.82 inches mercury absolute.

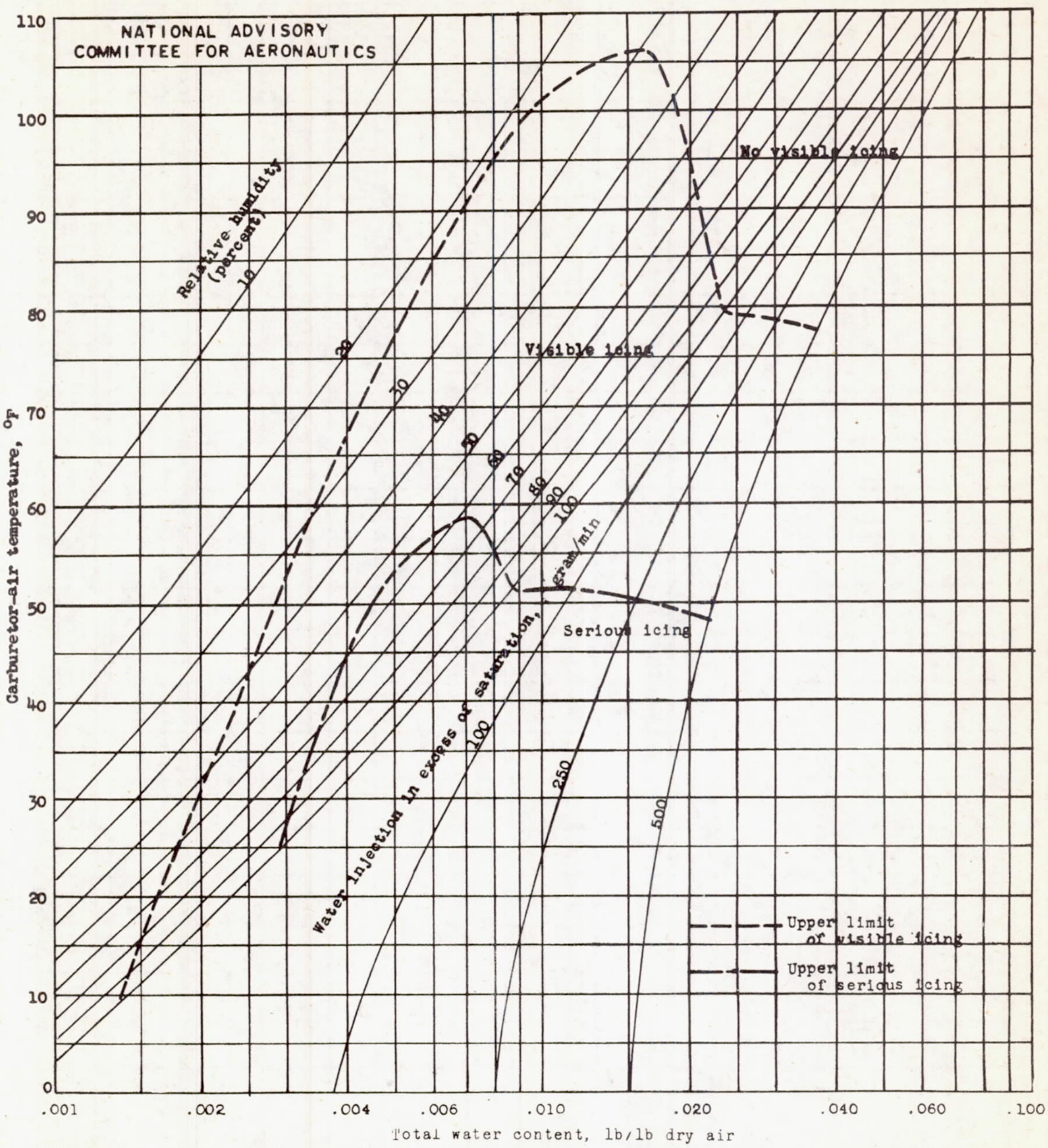
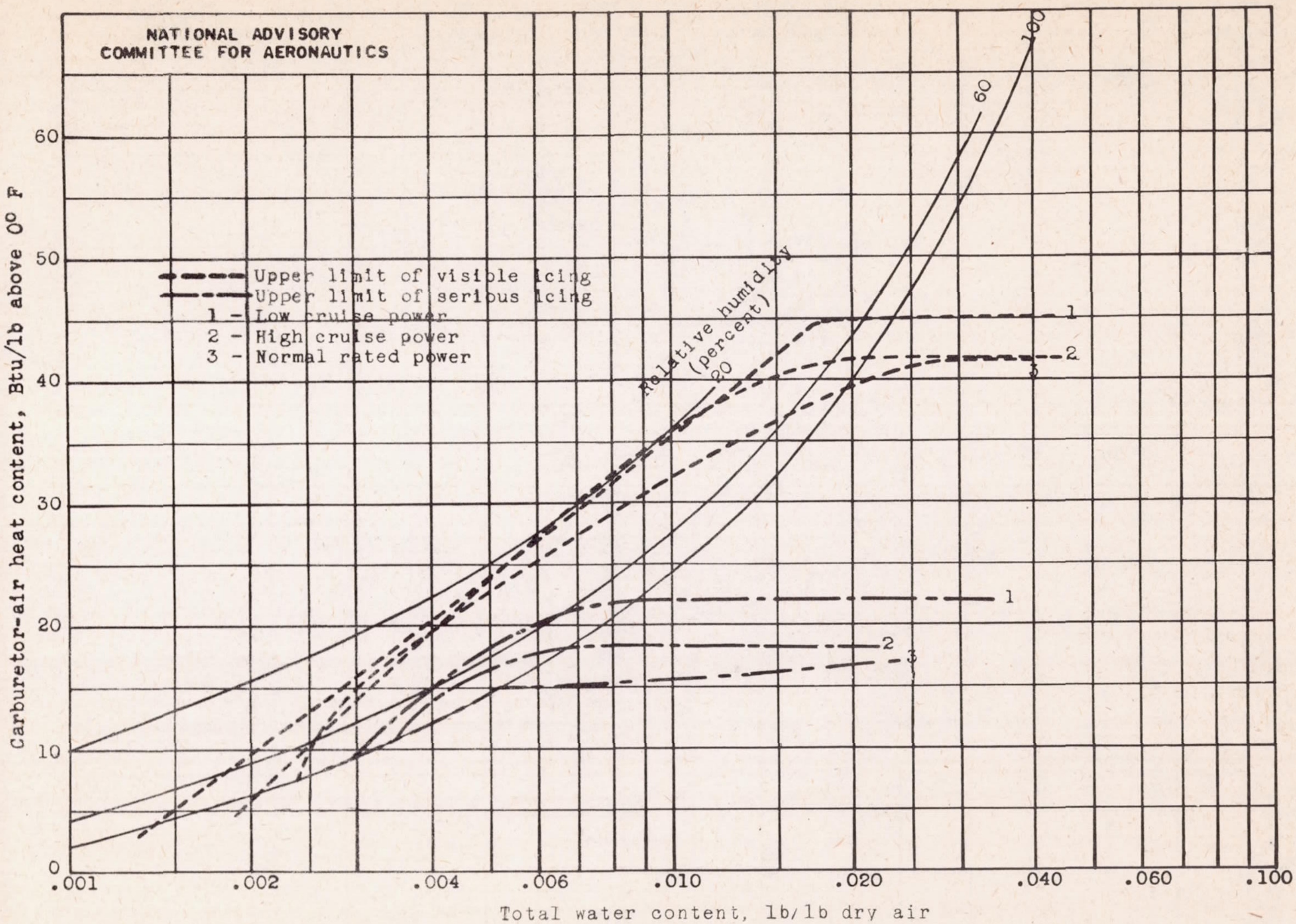
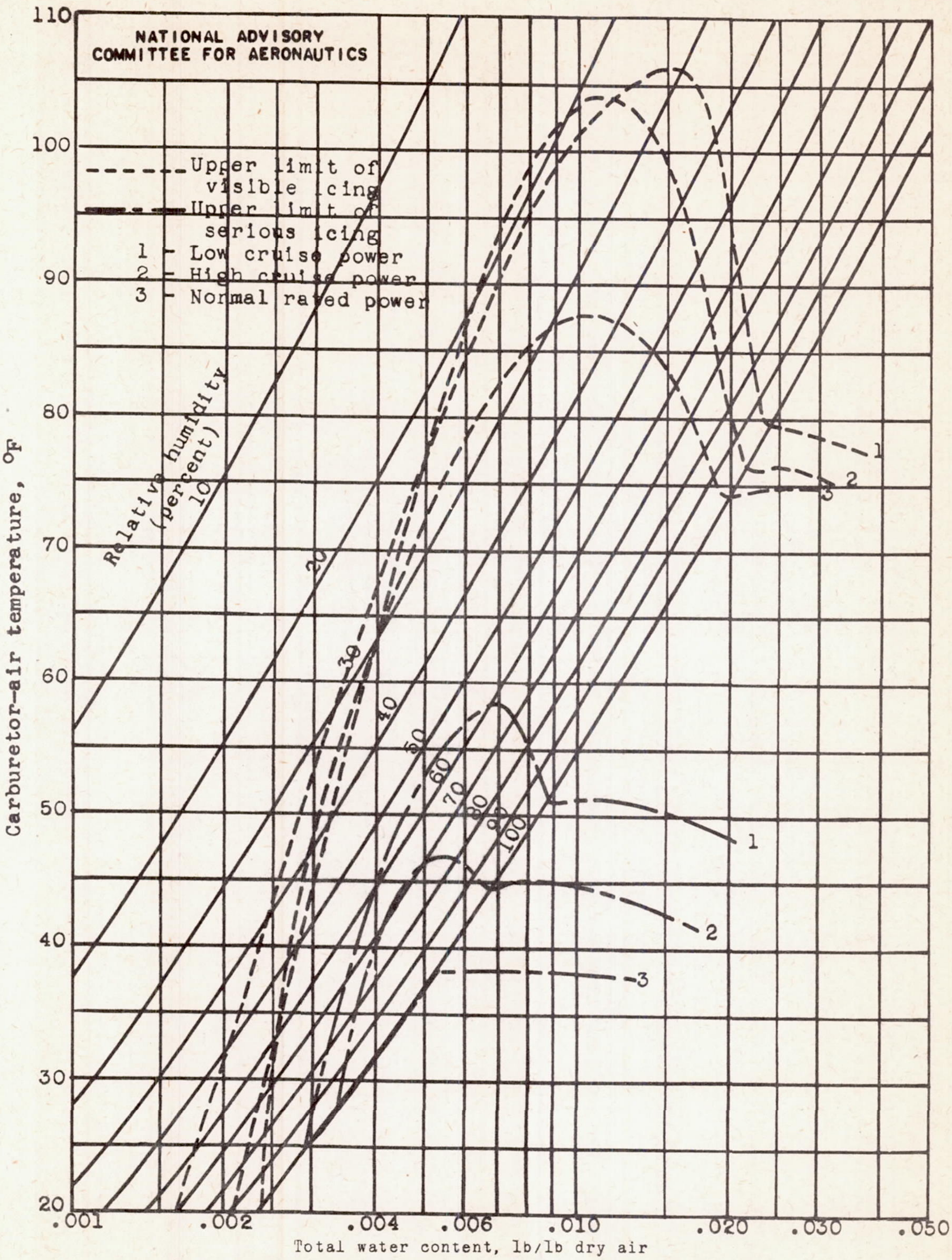


Figure 6. - Limiting-icing conditions of carburetor-air temperature and water content at simulated low cruising power obtained in test series 3. Initial air flow, 4620 pounds per hour; initial fuel-air ratio, 0.080; pressure altitude, 27.82 inches mercury absolute.



(a) Limiting-icing curves, variation of carburetor-air heat content with total water content.

Figure 7. - Effect of power conditions on icing characteristics of a carburetor and supercharger inlet elbow.



(b) Limiting-icing curves, variation of carburetor-air temperature with total water content.

Figure 7. - Concluded. Effect of power conditions on icing characteristics of a carburetor and supercharger inlet elbow.

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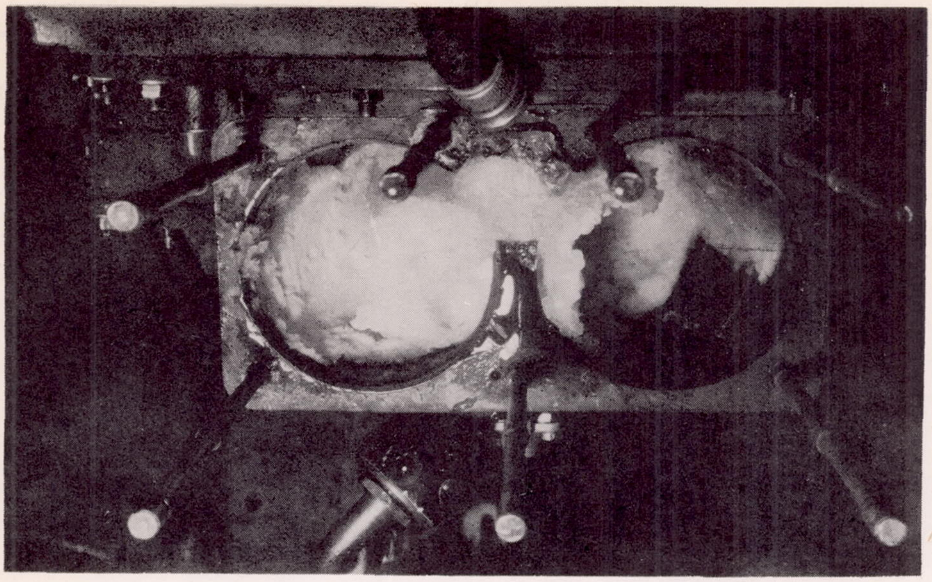
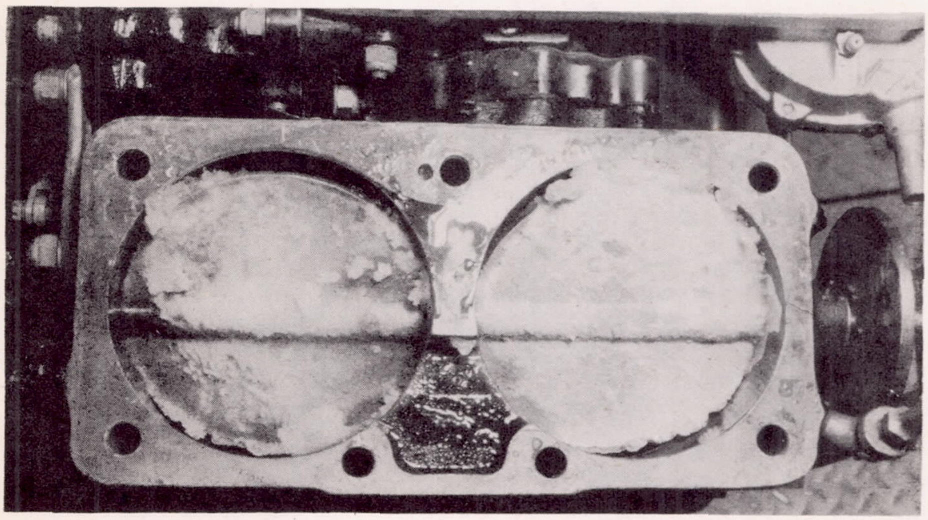


(a) Icing in supercharger inlet elbow. Carburetor-air temperature, 40° F; relative humidity, 100 percent; simulated-rain injection, 350 grams per minute; icing period, 6 minutes.



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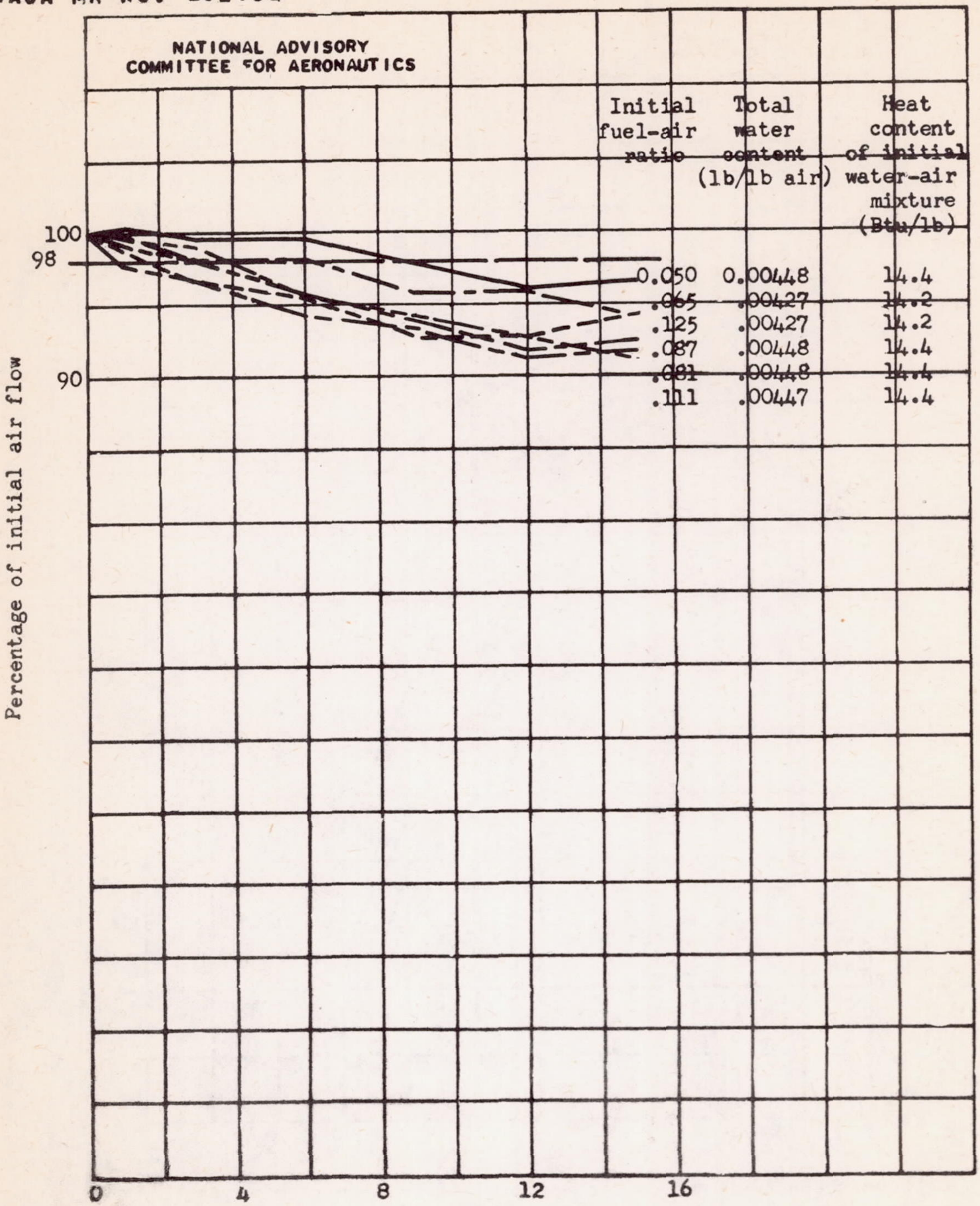
(b) Icing on carburetor throttles. Carburetor-air temperature, 37° F; relative humidity, 100 percent; simulated-rain injection, 650 grams per minute; icing period, 1 minute.

Figure 8. - Typical induction-system icing of carburetor and supercharger inlet-elbow assembly at 60 percent normal rated engine power.



(a) Relative humidity, 80 percent; no simulated-rain injection.

Figure 9. - Effect of varying fuel-air ratio on the icing characteristics of carburetor and accessory housing assembly obtained in test series 4. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; carburetor-air temperature, 40° F.

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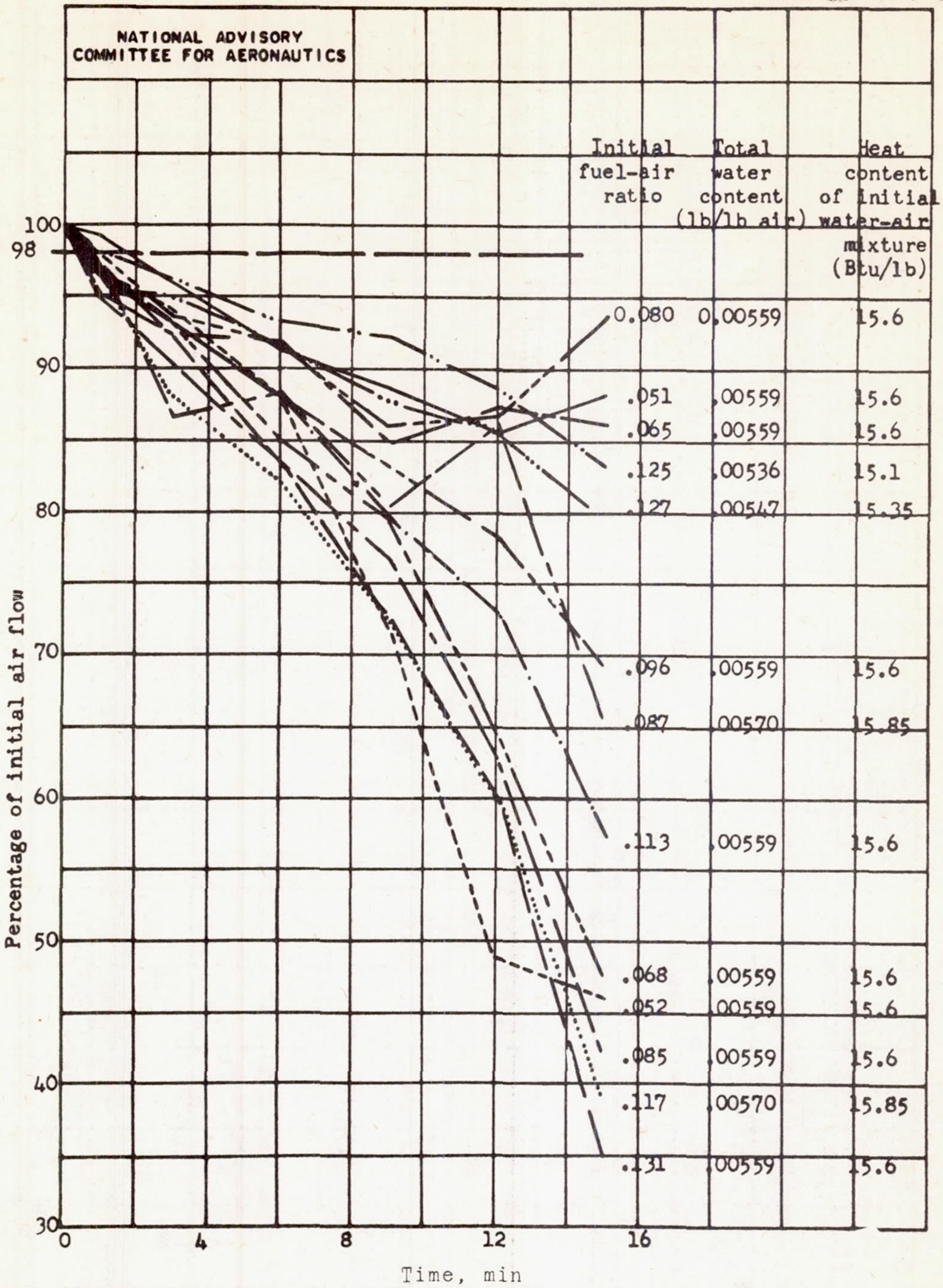

(b) Relative humidity, 100 percent; no simulated-rain injection.

Figure 9. - Continued. Effect of varying fuel-air ratio on the icing characteristics of carburetor and accessory housing assembly obtained in test series 4. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; carburetor-air temperature, 40° F.

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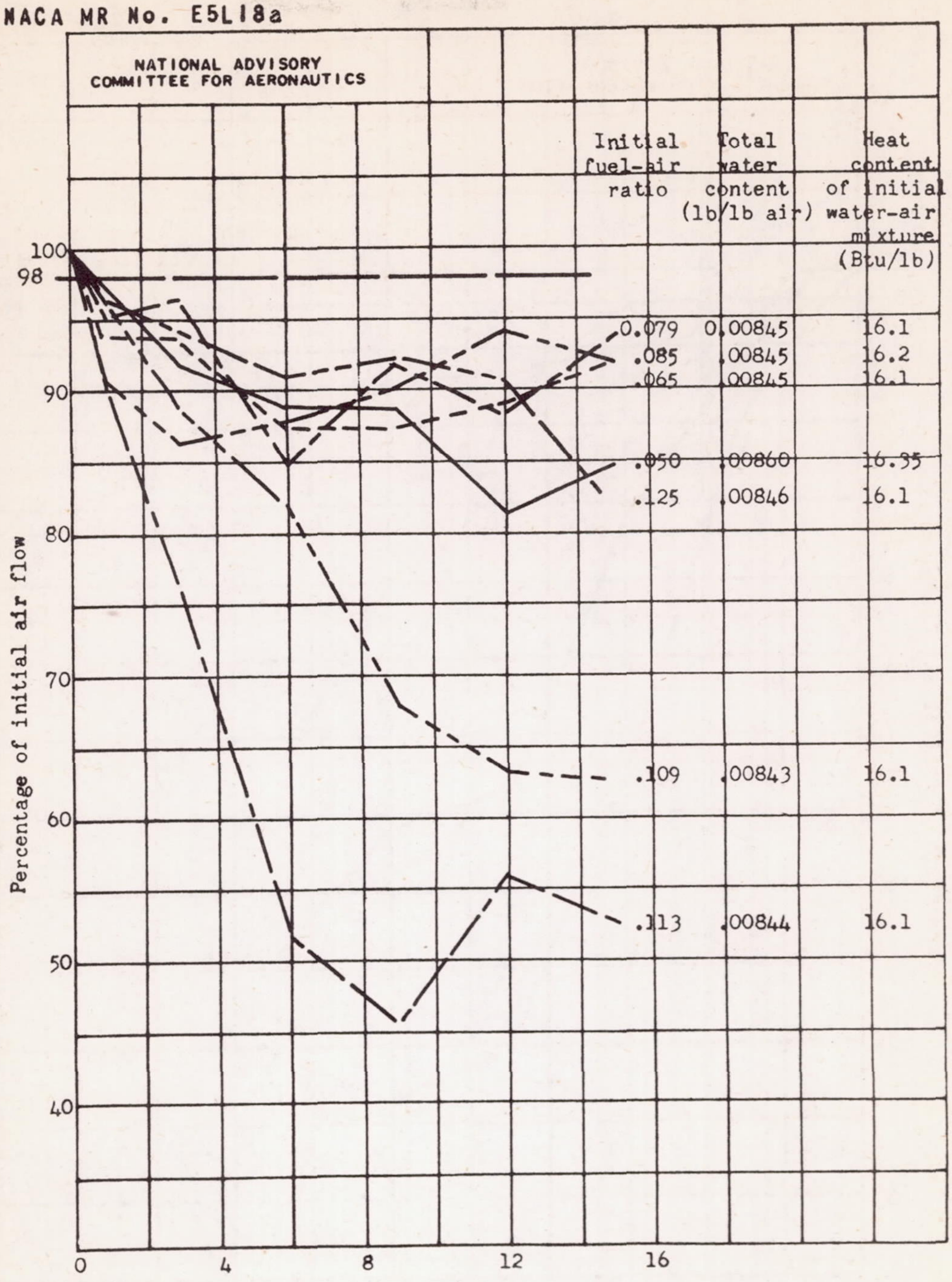
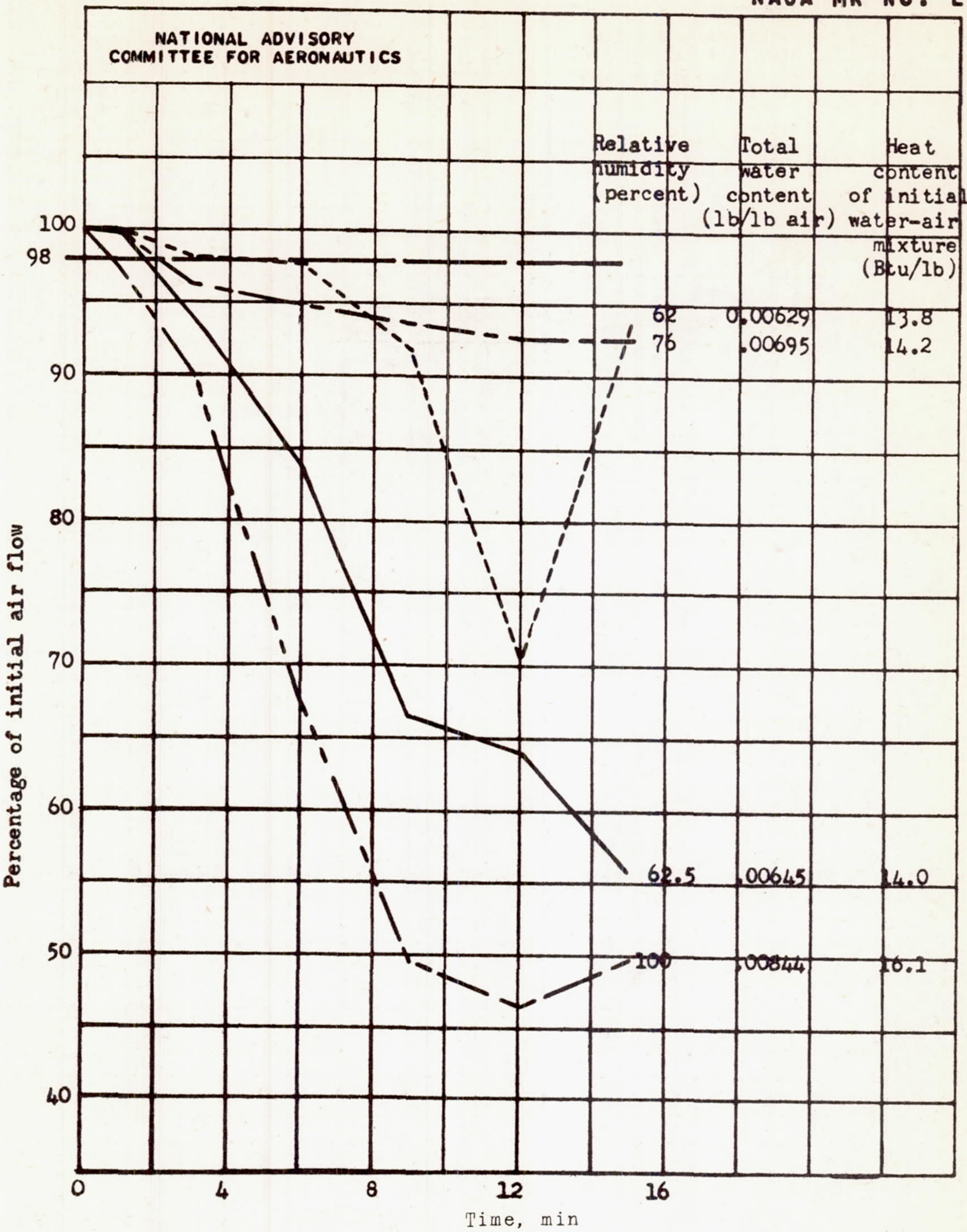


(c) Relative humidity, 100 percent; simulated-rain injection, 100 grams per minute; water temperature, 40° F.

Figure 9. - Concluded. Effect of varying fuel-air ratio on the icing characteristics of carburetor and accessory housing assembly obtained in test series 4. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; carburetor-air temperature, 40° F.



(a) Carburetor-air temperature, 40° F.

Figure 10. - Effect of varying relative humidity in the presence of free water on icing characteristics of carburetor and accessory housing assembly obtained in test series 5. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; fuel-air ratio, 0.080; simulated-rain injection, 100 grams per minute; water temperature, 40° F.

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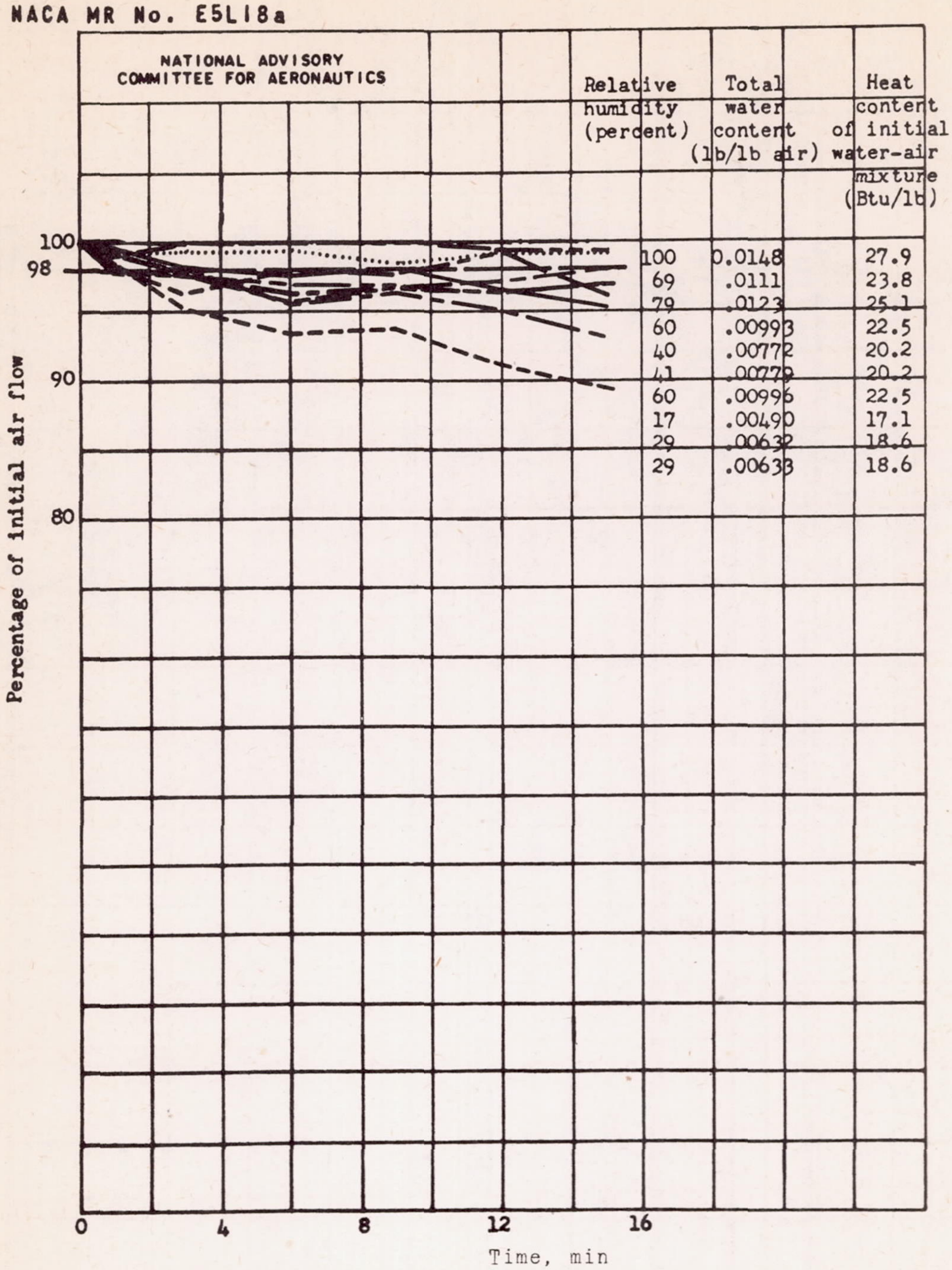
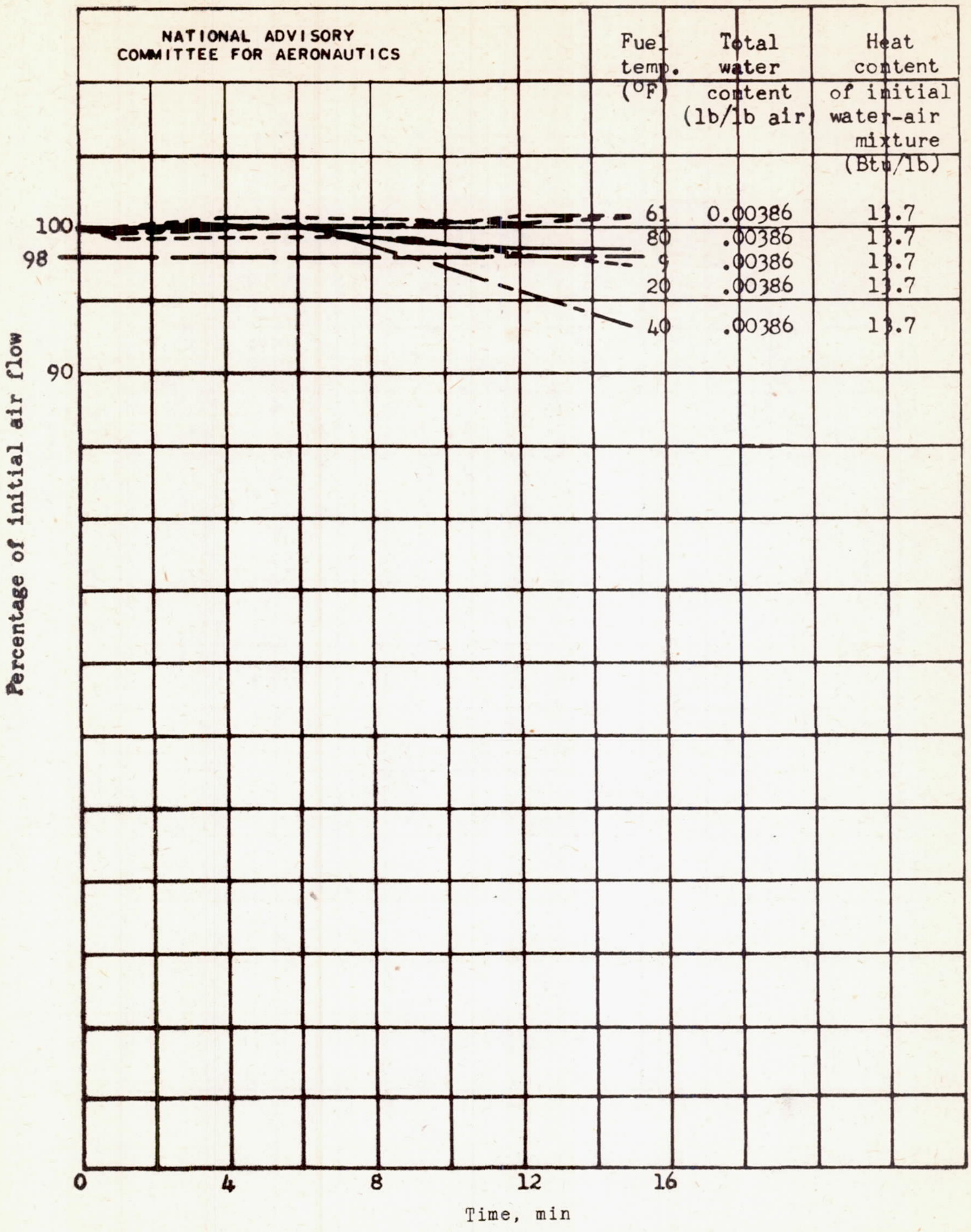


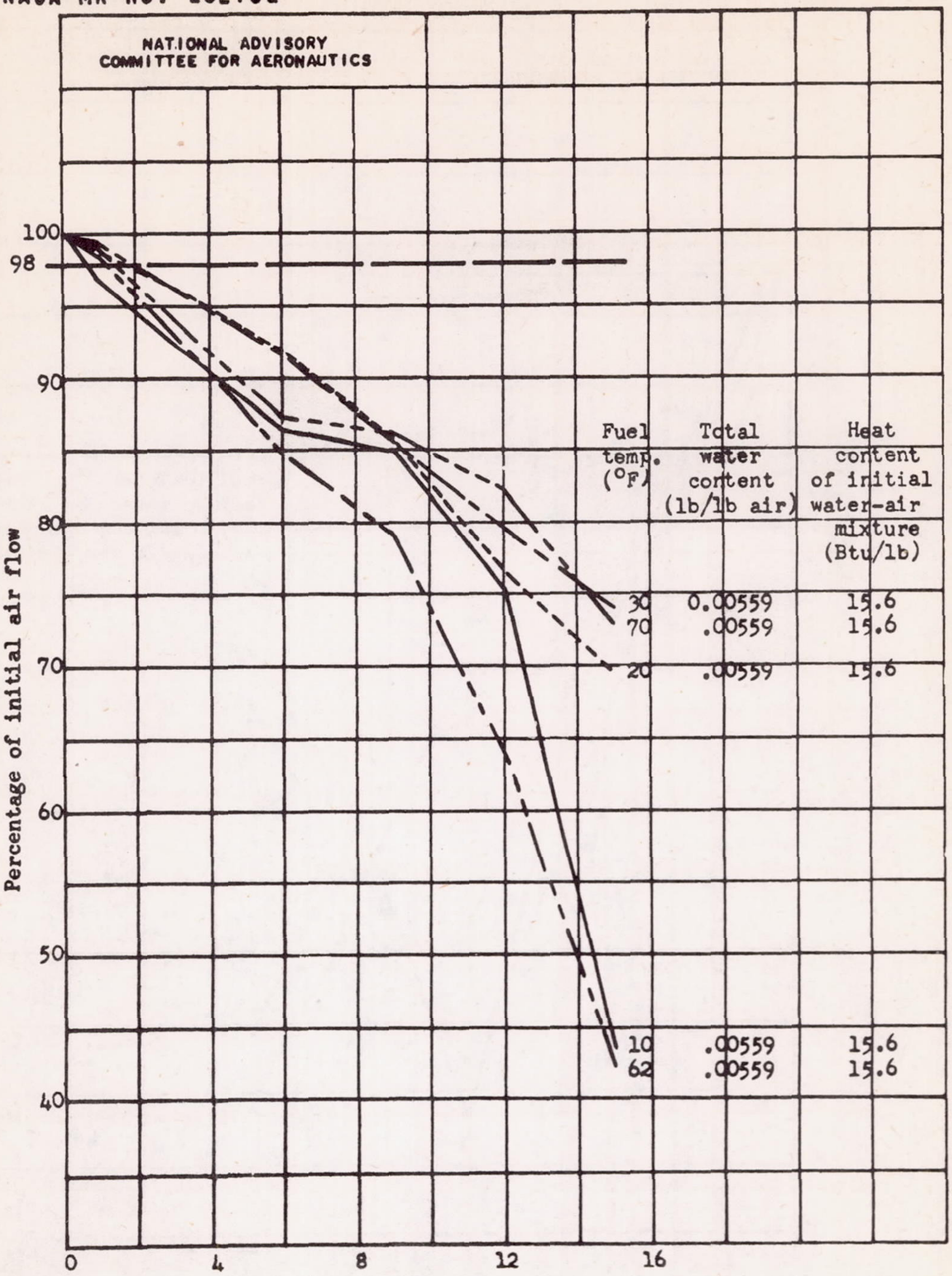
(b) Carburetor-air temperature, 60° F.

Figure 10. - Concluded. Effect of varying relative humidity in the presence of free water on icing characteristics of carburetor and accessory housing assembly obtained in test series 5. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; fuel-air ratio, 0.080; simulated-rain injection, 100 grams per minute; water temperature, 40° F.



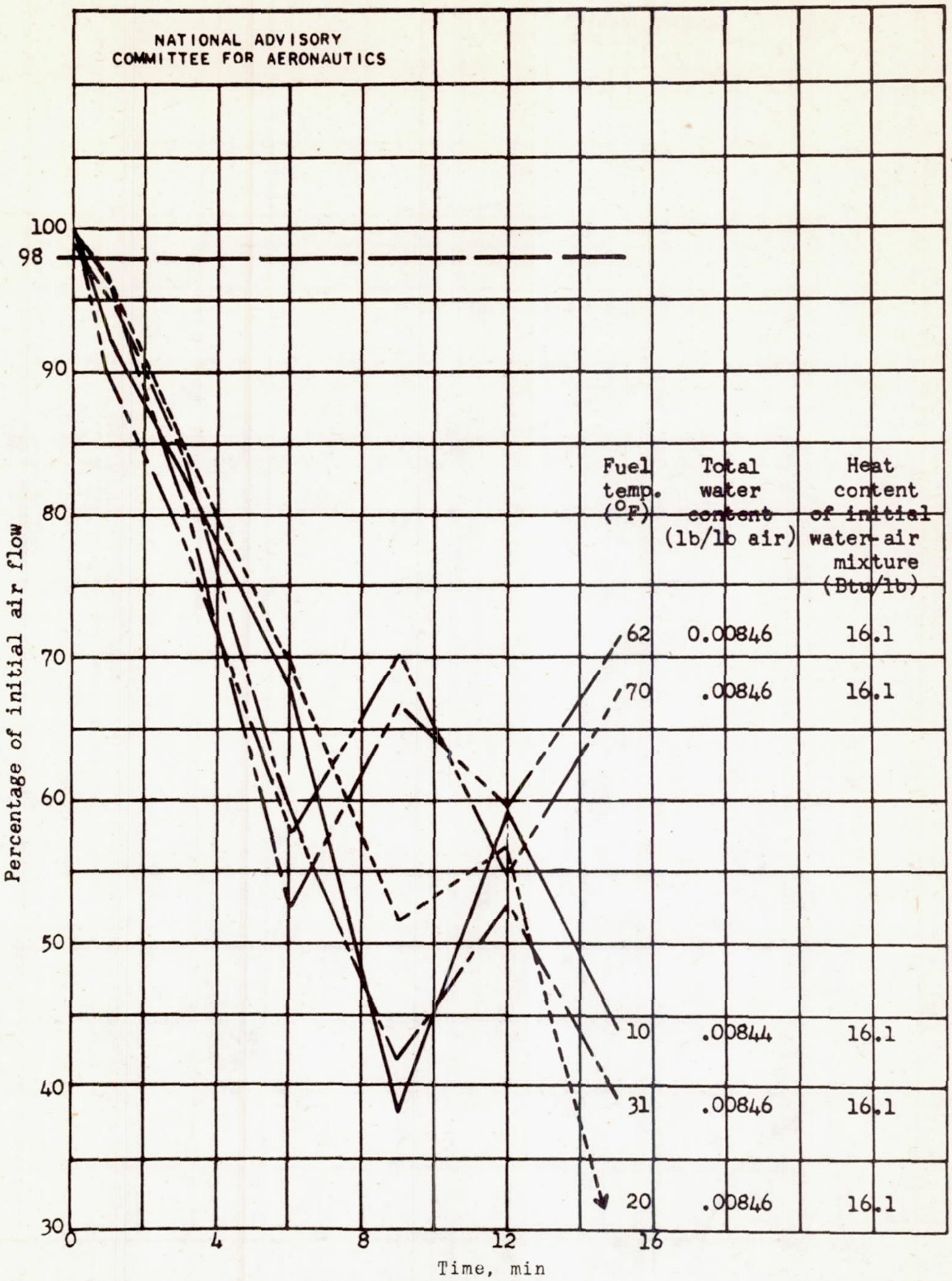
(a) Relative humidity, 69 percent; no simulated-rain injection.

Figure 11. - Effect of varying fuel temperature on icing characteristics of carburetor and accessory housing assembly obtained in test series 6. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel-air ratio, 0.080; carburetor-air temperature, 40° F.



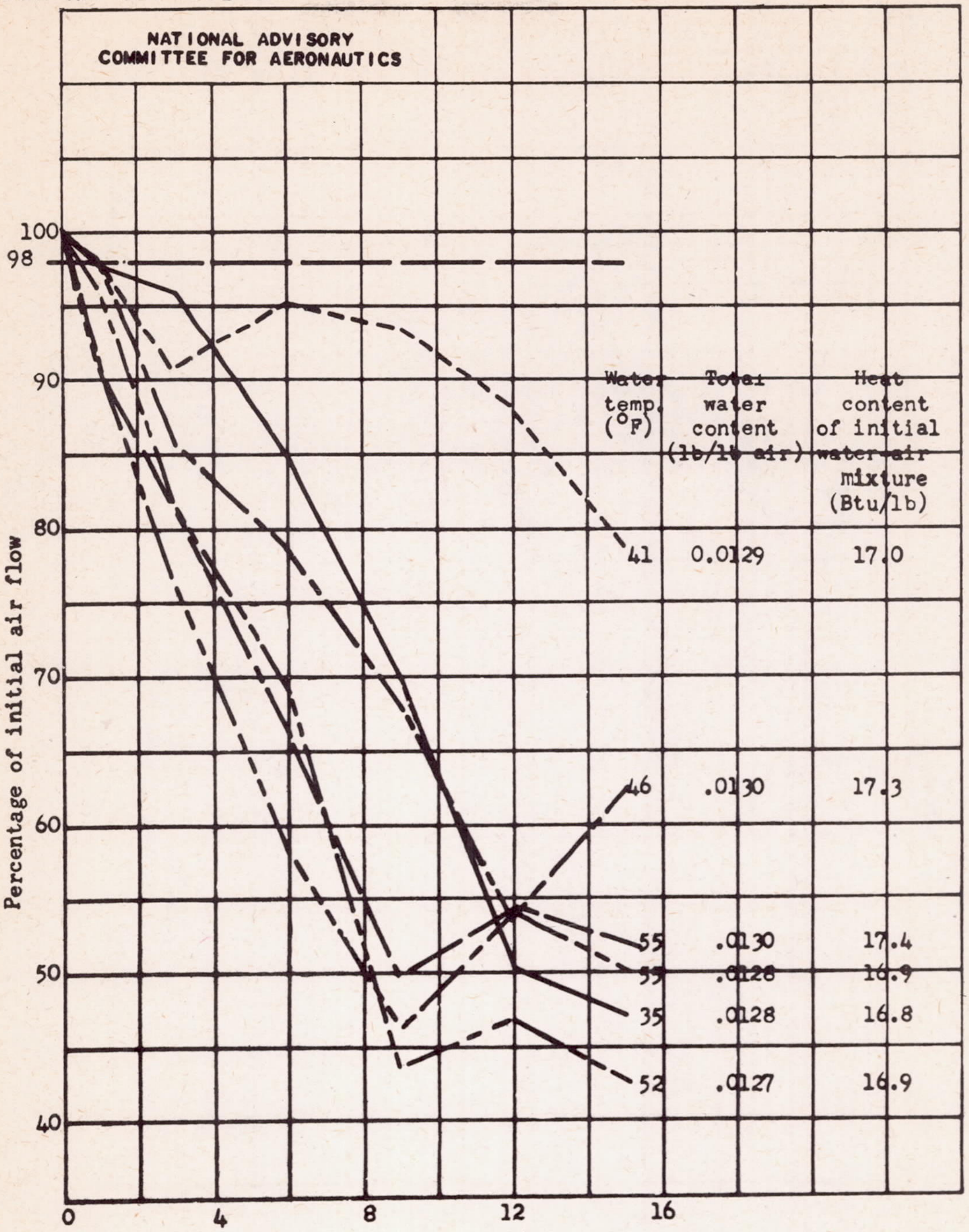
(b) Relative humidity, 100 percent; no simulated-rain injection.

Figure 11. - Continued. Effect of varying fuel temperature on icing characteristics of carburetor and accessory housing assembly obtained in test series 6. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel-air ratio, 0.080; carburetor-air temperature, 40° F.



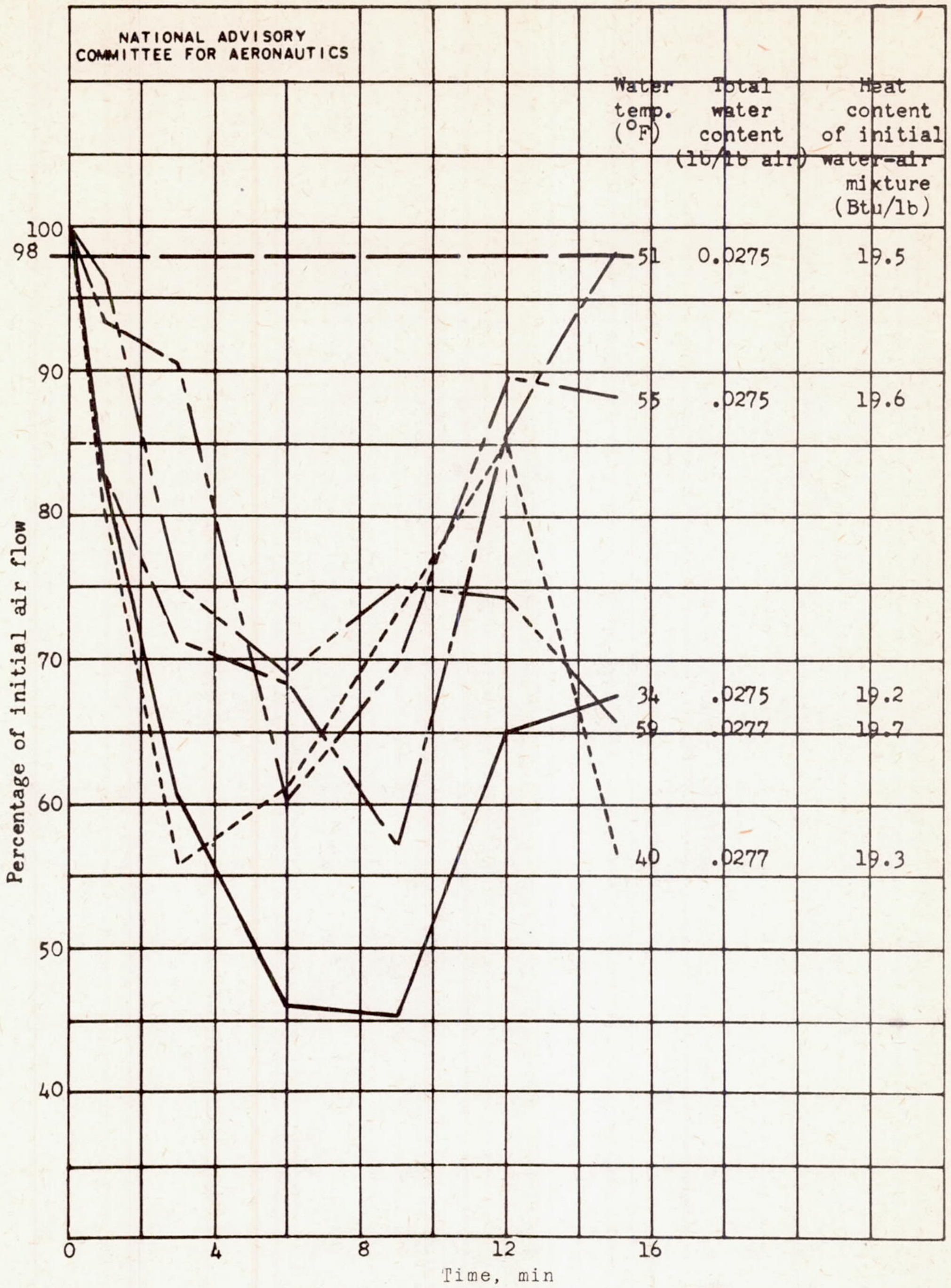
(c) Relative humidity, 100 percent; simulated-rain injection, 100 grams per minute; water temperature, 40° F.

Figure 11. - Concluded. Effect of varying fuel temperature on icing characteristics of carburetor and accessory housing assembly obtained in test series 6. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel-air ratio, 0.080; carburetor-air temperature, 40° F.



(a) Carburetor-air temperature, 40° F; simulated-rain injection, 250 grams per minute.

Figure 12. - Effect of varying free-water injection temperatures on icing characteristics of carburetor and accessory housing assembly obtained in test series 7. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; fuel-air ratio, 0.080; relative humidity, 100 percent.



(b) Carburetor-air temperature, 40° F; simulated-rain injection, 750 grams per minute.

Figure 12. - Continued. Effect of varying free-water injection temperatures on icing characteristics of carburetor and accessory housing assembly obtained in test series 7. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; fuel-air ratio, 0.080; relative humidity, 100 percent.

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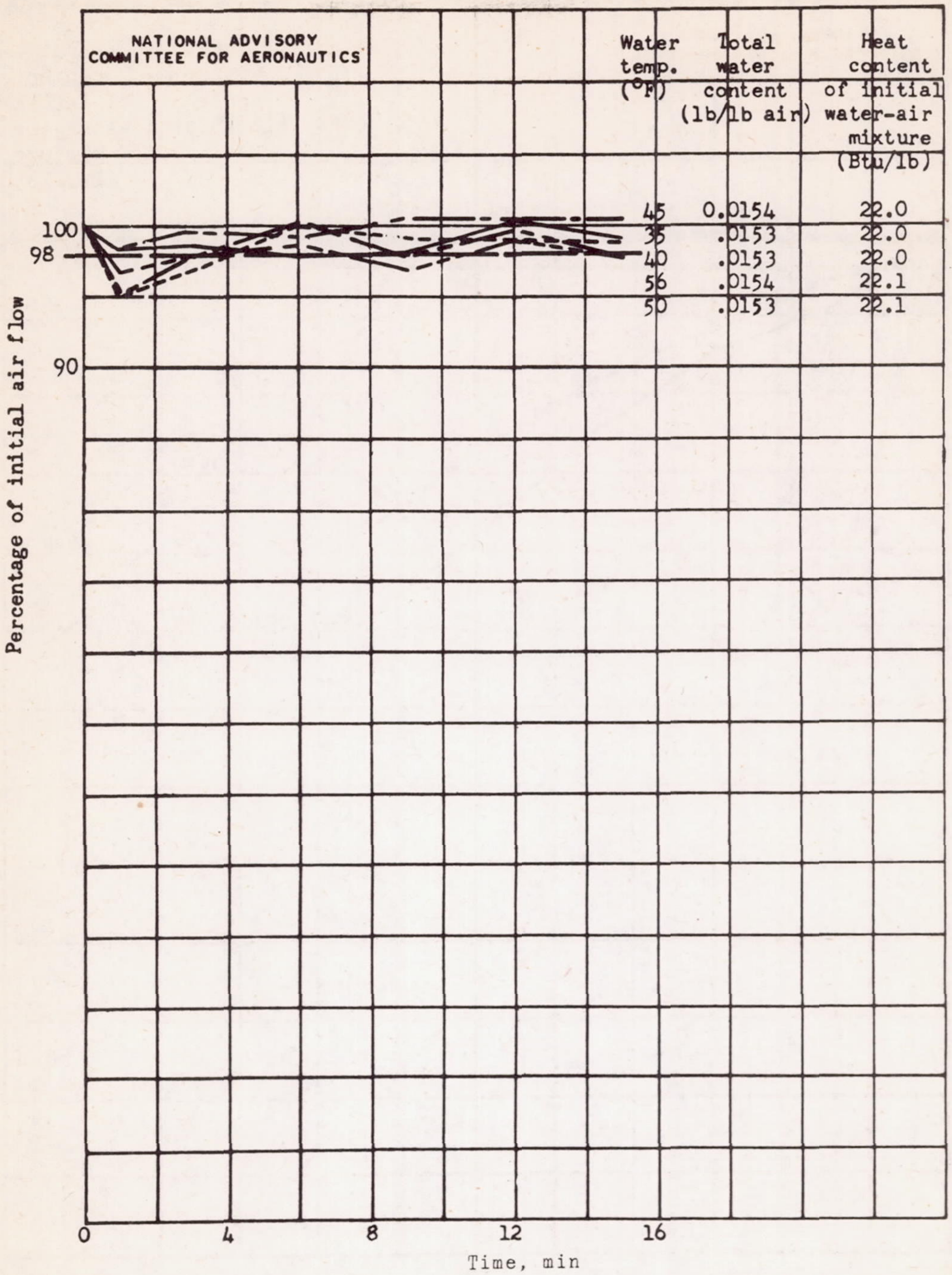
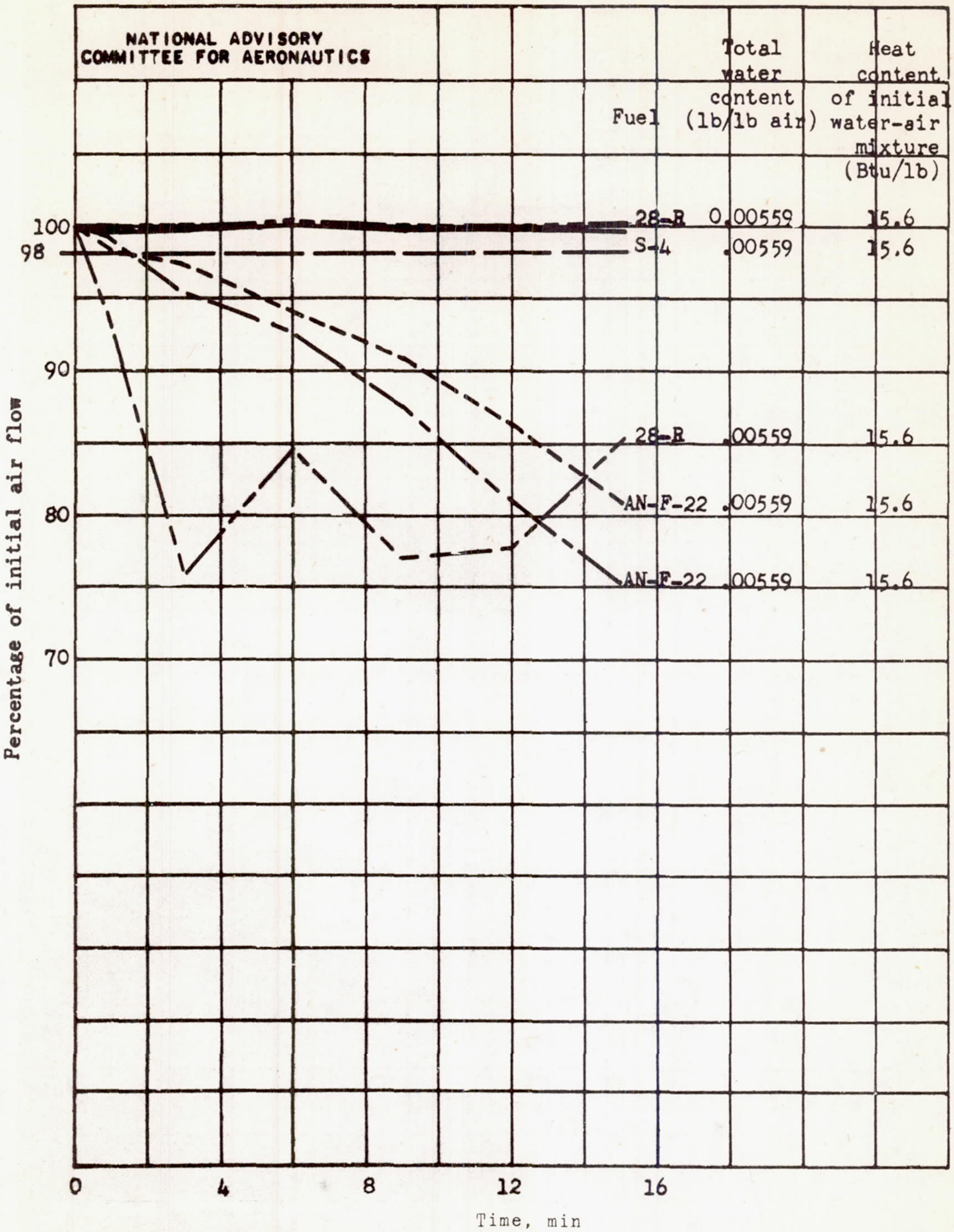


(c) Carburetor-air temperature, 50° F; simulated-rain injection, 250 grams per minute.

Figure 12. - Concluded. Effect of varying free-water injection temperatures on icing characteristics of carburetor and accessory housing assembly obtained in test series 7. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel temperature, 40° F; fuel-air ratio, 0.080; relative humidity, 100 percent.



(a) Carburetor-air temperature, 40° F; relative humidity, 100 percent; no simulated-rain injection.

Figure 13. - Effect of varying fuel grade on icing characteristics of carburetor and accessory housing assembly obtained in test series 8. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel-air ratio, 0.080; average fuel temperature, 75° F.

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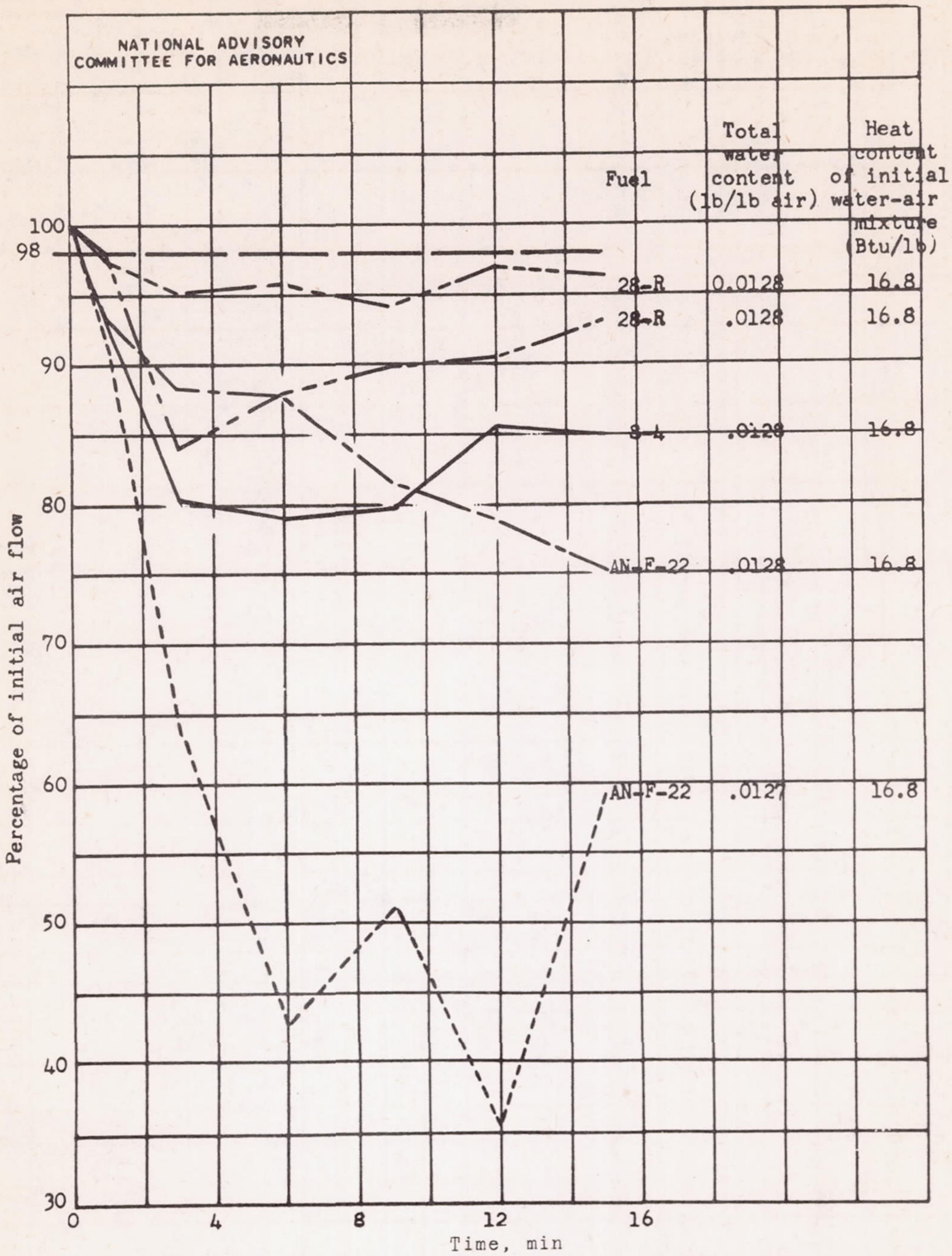
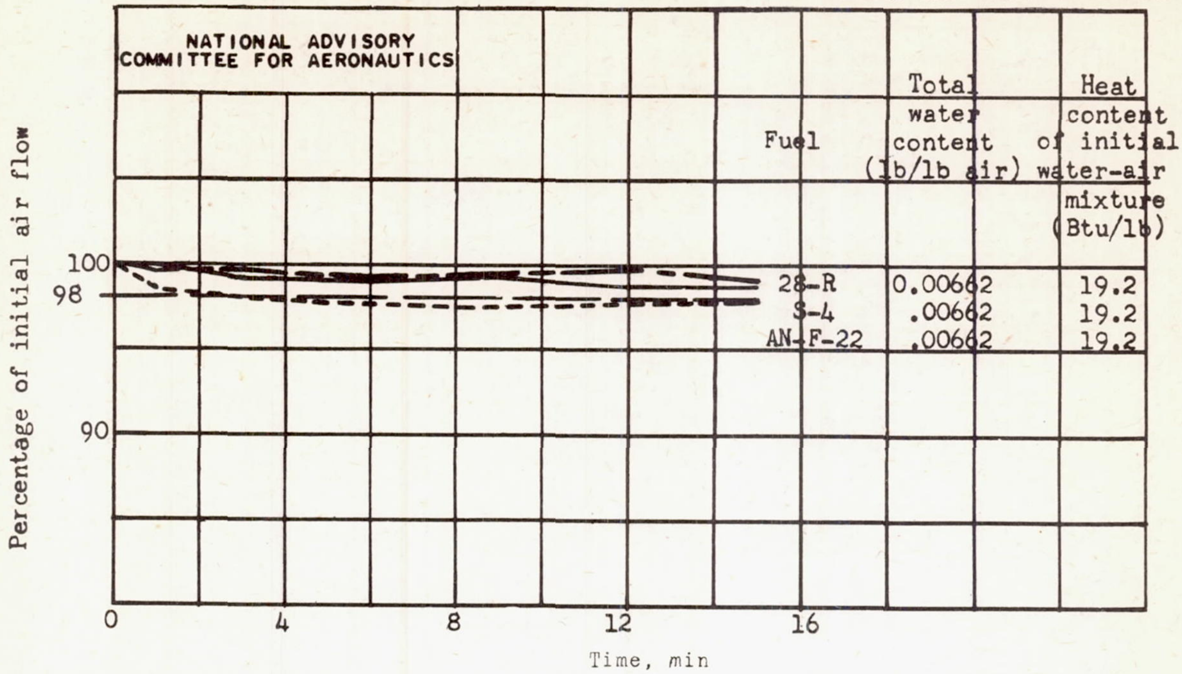
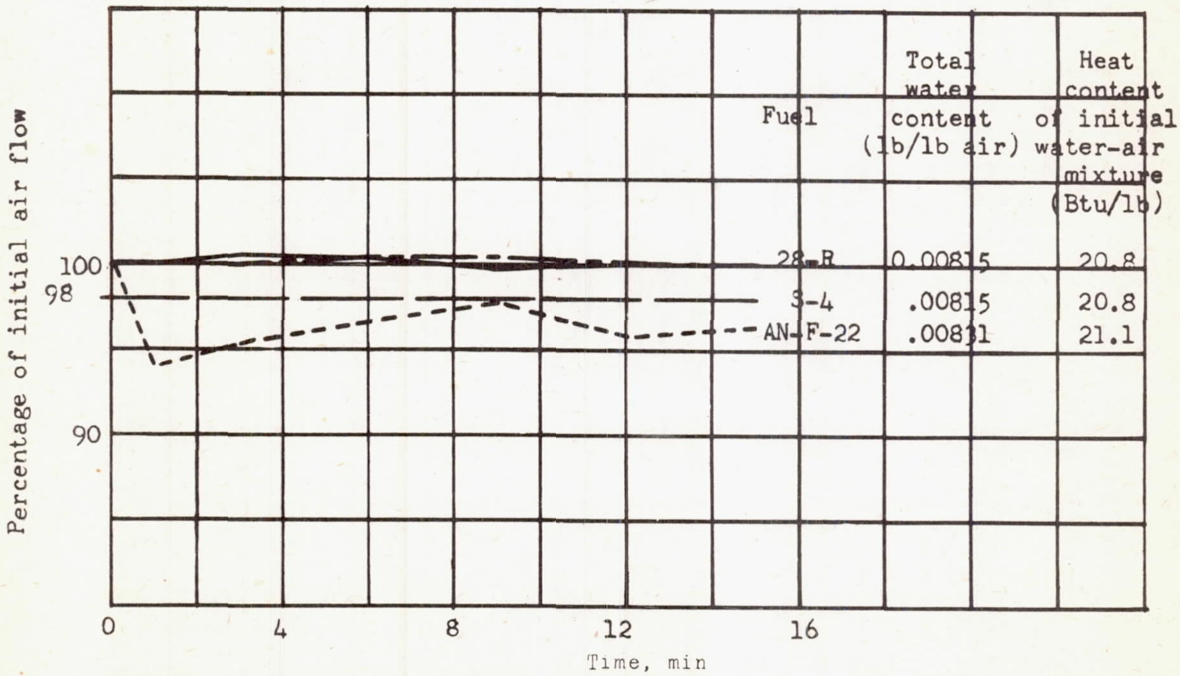


(b) Carburetor-air temperature, 40° F; relative humidity, 100 percent; simulated-rain injection, 250 grams per minute; water temperature, 40° F.

Figure 13. - Continued. Effect of varying fuel grade on icing characteristics of carburetor and accessory housing assembly obtained in test series 8. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel-air ratio, 0.080; average fuel temperature, 75° F.



(c) Carburetor-air temperature, 50° F; relative humidity, 81 percent; no simulated-rain injection.



(d) Carburetor-air temperature, 50° F; relative humidity, 100 percent; no simulated-rain injection.

Figure 13. - Continued. Effect of varying fuel grade on icing characteristics of carburetor and accessory housing assembly obtained in test series 8. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel-air ratio, 0.080; average fuel temperature, 75° F.

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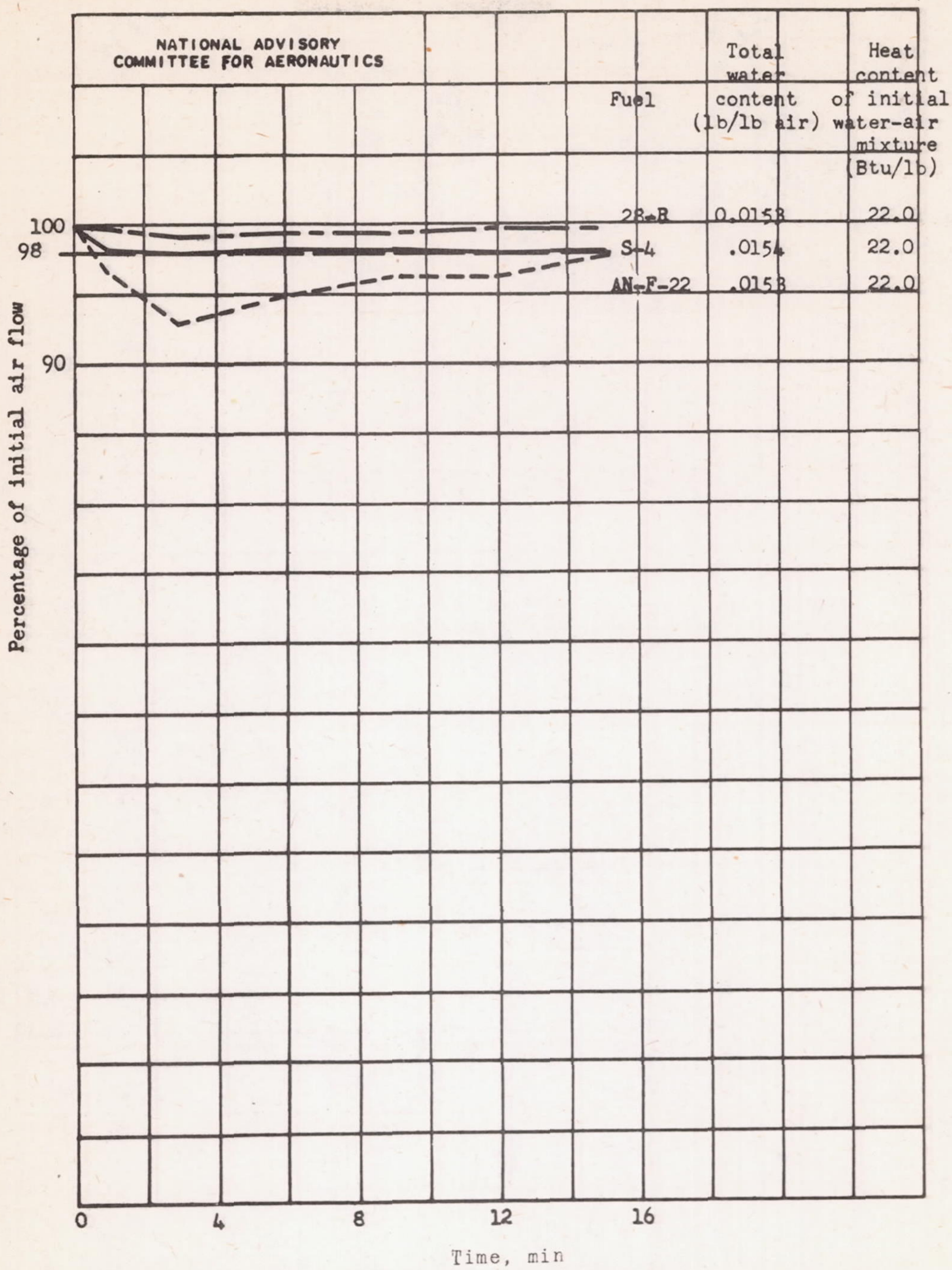

(e) Carburetor-air temperature, 50° F; relative humidity, 100 percent; simulated-rain injection, 250 grams per minute; water temperature, 40° F.

Figure 13. - Concluded. Effect of varying fuel grade on icing characteristics of carburetor and accessory housing assembly obtained in test series 8. Initial test conditions: engine speed, 2200 rpm; manifold pressure, 30.2 inches mercury absolute; carburetor top-deck pressure, 27.80 inches mercury absolute; air flow, 4620 pounds per hour; fuel-air ratio, 0.080; average fuel temperature, 75° F.

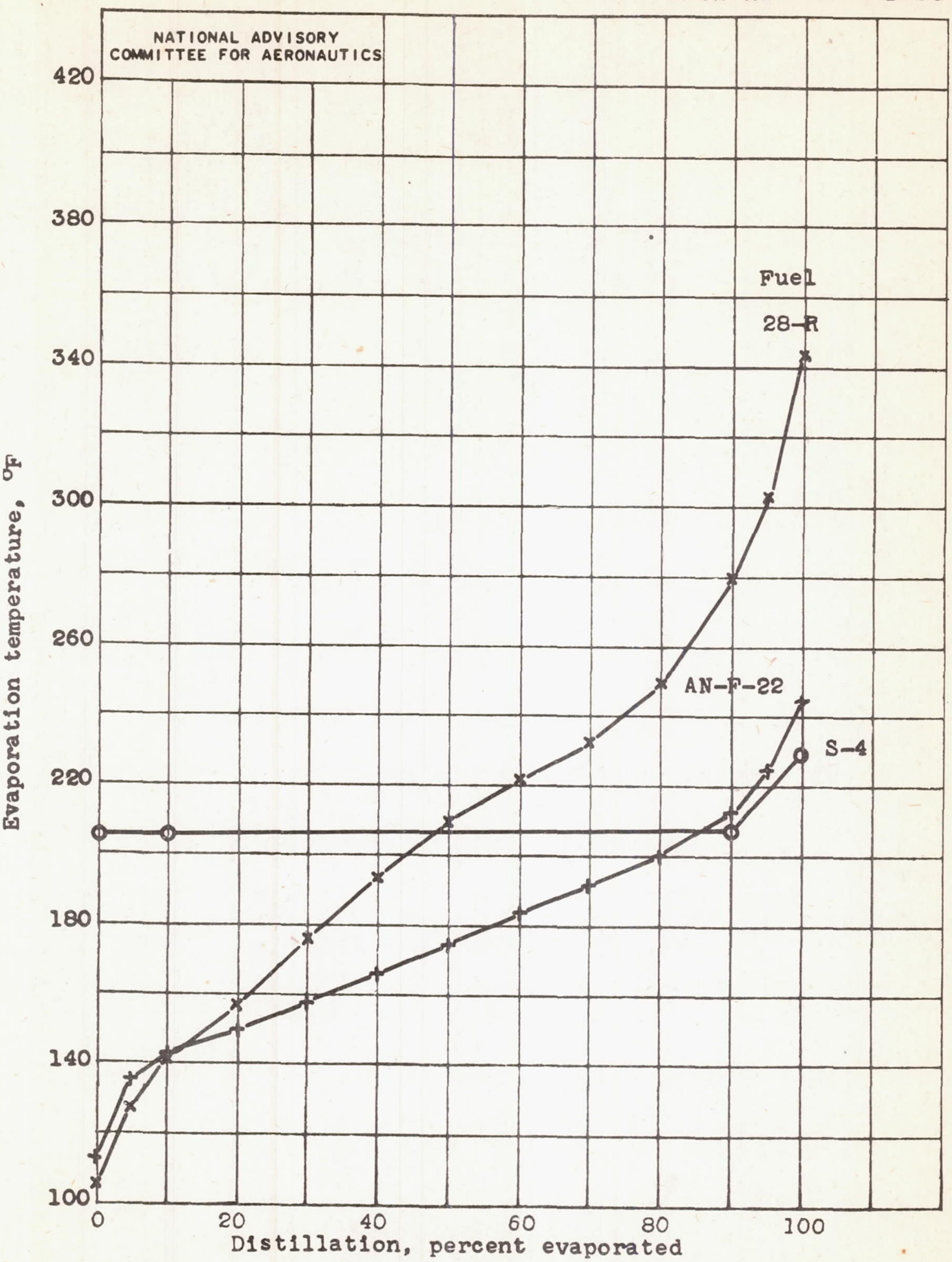

Figure 14. - Distillation curves for AN-F-22, 28-R, and S-4 reference fuel used in test series 8. Data from NACA Cleveland Fuel and Lubricants analytical laboratory.